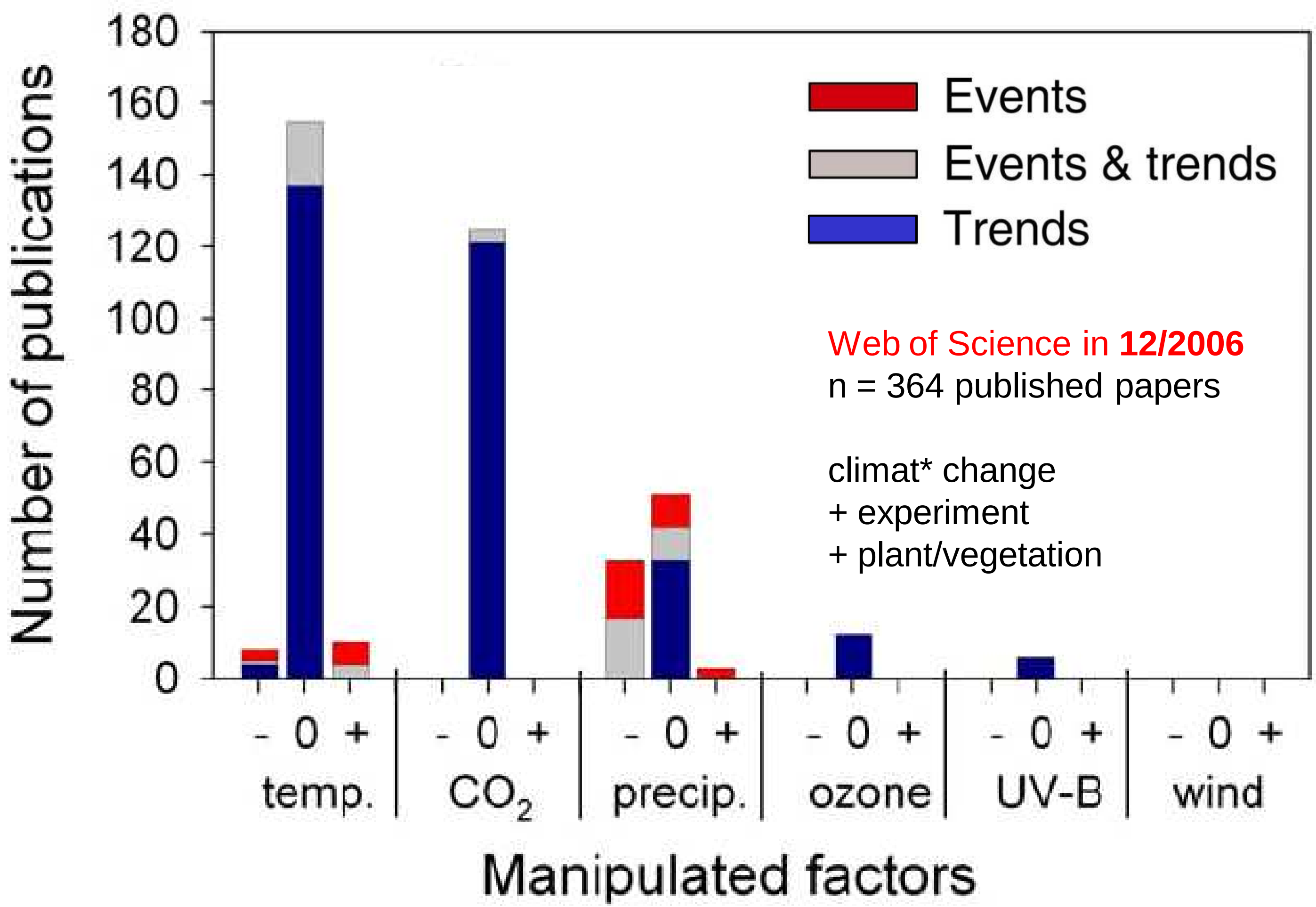
# *Climate extremes initiate plant regulating functions while maintaining productivity*

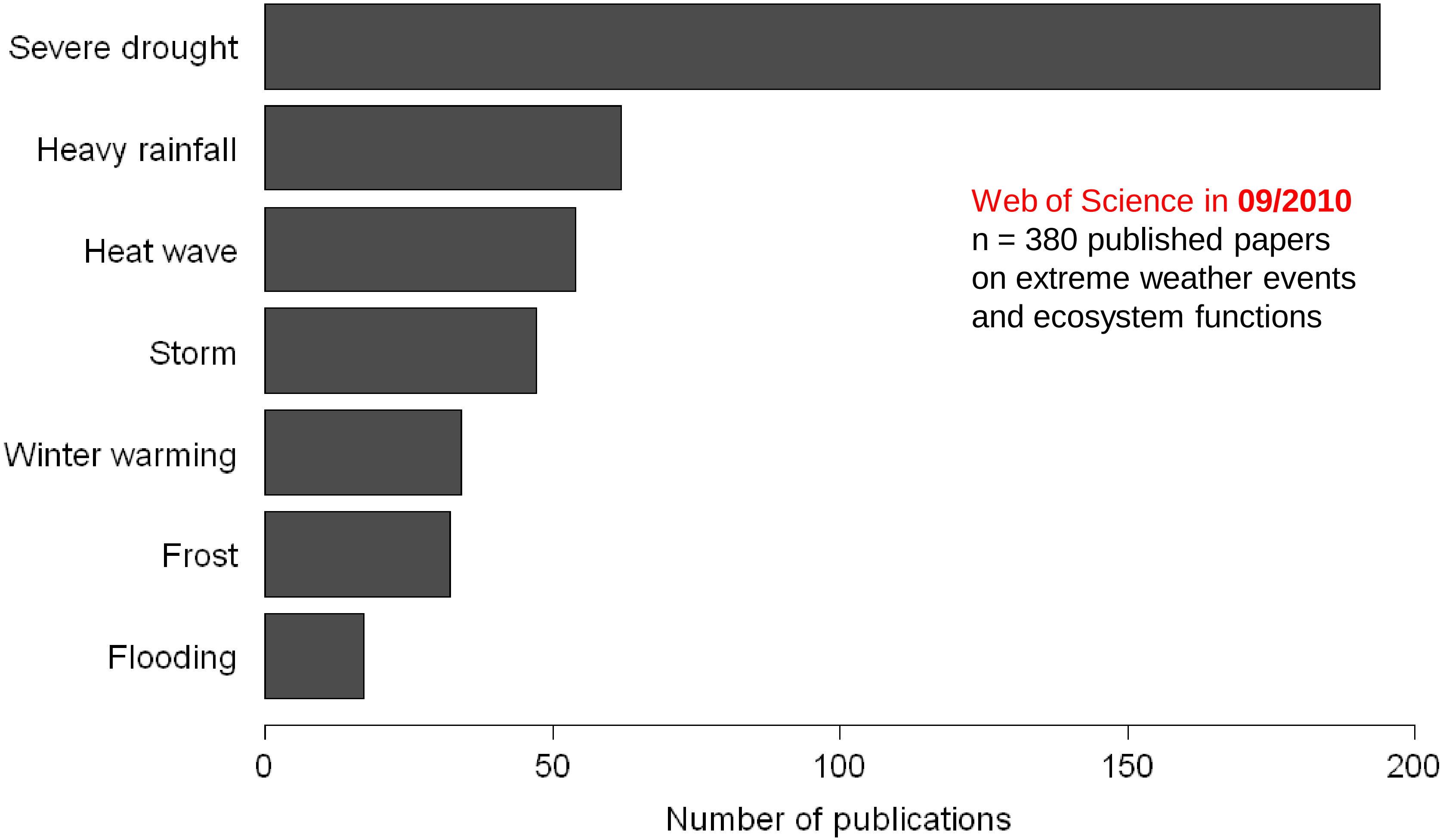

Prof. Dr. Anke Jentsch, Geoecology / Physical Geography, University of Koblenz-Landau

# *Most ecological experiments in climate change research manipulate temperature and CO2*




Jentsch, Kreyling, Beierkuhnlein (2007) *Frontiers in Ecology Environment*

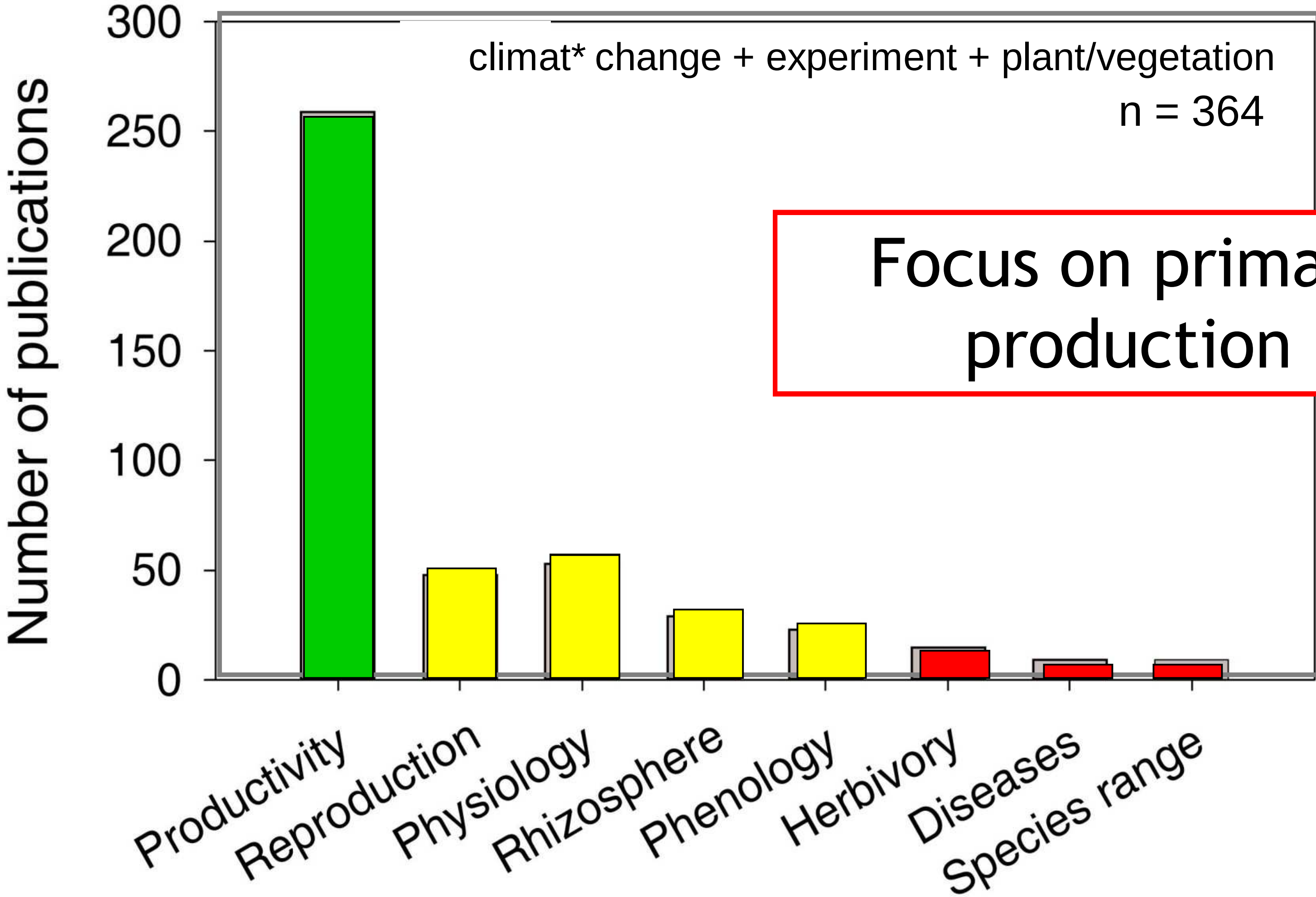
# *Most ecological experiments in extreme events research manipulate precipitation regime*

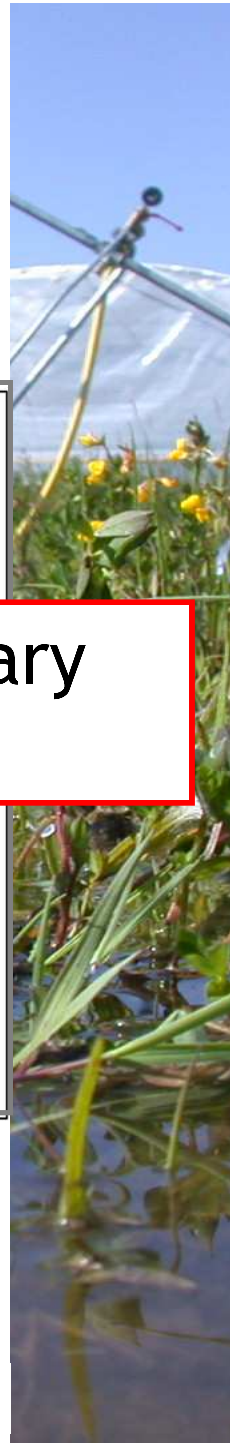



*Jentsch et al (accept condit) J Ecol*

# *Response Parameter Climate Change*

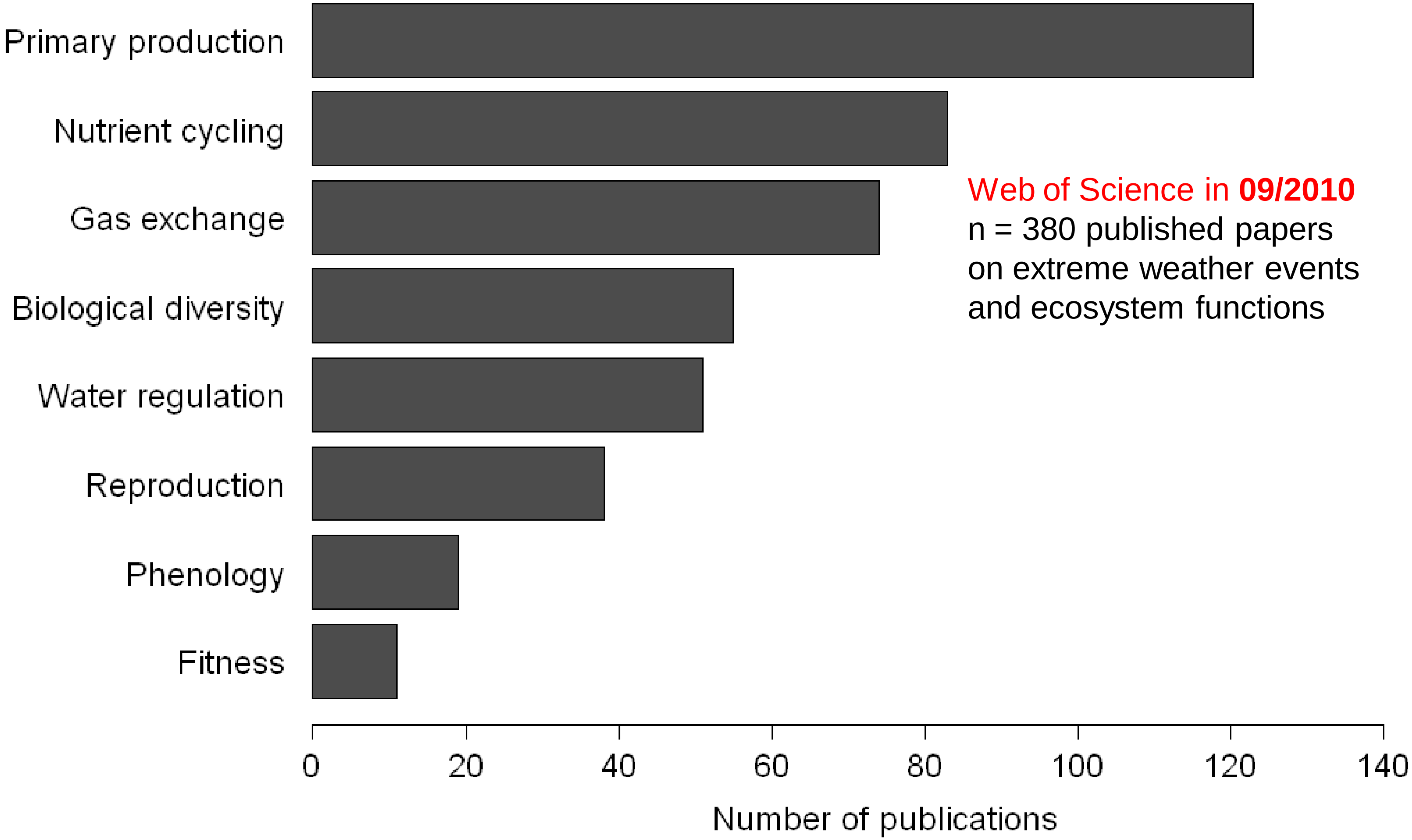
## *(ISI Web of Science 12/2006)*



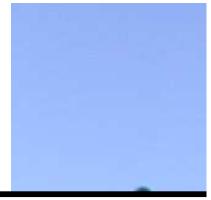
Jentsch et al. (2007) *Frontiers in Ecology and the Environment*

# *Response Parameter Extreme Weather Events*
## *(ISI Web of Science 12/2009)*




*Jentsch et al (accept condit) J Ecol*

# Bayreuth EVENT Experiments



## EVENT I

Since 2005, 150 plots

Constructed communities (homogenized soil, # plants, 2- factorial), three types of control, biodiversity; drought, heavy rain, frost-thaw cycles

## EVENT II

Since 2008, 150 plots

Semi-natural grassland, diverse, multi-factorial; land use intensity differs, drought, heavy rain, winter / summer warming, + winter precipitation

## EVENT III

Since 2009, 3000 pots

Controlled pot experiment for European proveniences of key grass / tree species; drought, summer warming

## EVENT V

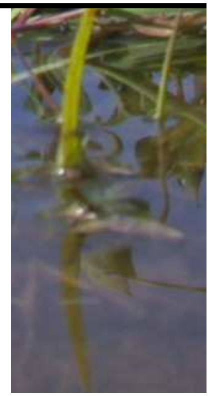
Since 1996,former BIODEPTH, 64 plots

Long-term reference system in constructed grassland starting at various levels of biodiversity; winter rain

## EVENT IV

Starts 2010

Controlled microcosms; soil moisture, soil warming, freeze-thaw cycles



EVENT

# Experiments

FORKAST

# Experiments

| | | EVENT I | EVENT II | EVENT III | EVENT IV | EVENT V |
|---|---|---|---|---|---|---|
| Extremes | Summer precip. | X | X | X | | |
| | Summer drought | X | X | X | | |
| | Frost-thaw-cycles | X | | | X | |
| Trends | Summer warming | | X | X | | |
| | Winter warming | X | X | | | |
| | + Winter-rain | | X | | | X |
| Controls | Ambient control | X | X | | X | X |
| | Artefact control | X | | X | | |
| | Average control | X | X | | | |
| Combin. | Warming / drought | | X | X | | |
| | Warming / heavy rain | | X | X | | |
| | Warming / land use | | X | | | |

Jentsch, A., Beierkuhnlein C (2010) Simulating the future Responses of ecosystems, key species and European provenances to expected climatic trends and events. NAL NF 112 (384): 89-98

# Experiments

| | EVENT I | EVENT II | EVENT III | EVENT IV | EVENT V |
|---|---|---|---|---|---|
| Begin | 2005 | 2008 | 2008 | 2010 | 1996 / 2009 |
| # Replicates | 5 | 5 | 21 | 5 | 2 |
| # Plots | 150 | 225 | 2352 | 140 | 64 |
| Communities | grassland, shrubland | grassland | - | grassland, shrubland | grassland |
| Functional Types | grasses, herbs, legumes, shrubs | grasses, herbs, legumes | grasses, trees, shrubs | grasses, shrubs | grasses, herbs, legumes |
| species diversity (# species / plot) | artificial 1, 2, 4 | natural 9 - 32 | none | artificial 1,2,4 | Init. 1 – 16, now 16 - 26 |
| Funct. diversity | 1, 2, 3 | none | none | 1, 2, 3 | 1, 2, 3 |
| Total # species | 10 | 55 | 10 | 4 | 54 |

**Biodiversity**

Jentsch, A., Beierkuhnlein C (2010) Simulating the future Responses of ecosystems, key species and European provenances to expected climatic trends and events. NAL NF 112 (384): 89-98

# Bayreuth EVENT Experiments

## EVENT I
Since 2005

Constructed communities (homogenized soil, # plants, 2- factorial), three types of control, biodiversity; drought, heavy rain, frost-thaw cycles

## EVENT II
Since 2008

Semi-natural grassland, diverse, multi-factorial; land use intensity differs, drought, heavy rain, winter / summer warming, + winter precipitation

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Since 2009

Controlled pot experiment for European proveniences of key grass / tree species; drought, summer warming

## EVENT IV
Since 1996,former BIODEPTH

Long-term reference system in constructed grassland starting at various levels of biodiversity; winter rain

## EVENT V
Starts 2010

Controlled microcosms; soil moisture, soil warming, freeze-thaw cycles

# *The EVENT Experiments*
# Effects of drought, heavy rain and freeze-thaw cycles on organisms and ecosystem functions


Mean annual temp.: 7,8 °C, mean annual precip: 709 mm, soil: homogenized, drained sandy loam, C/N-ratio: 15.4 – 20.2, pH: 5.5, site: 49°55’19“, 11°, 34’55“

# *Manipulating precipitation regime*

Extremeness of events was determined by statistical extremity with respect to a historical reference period (vegetation period March – Sept. 1961-2000) independent of its effects on organisms (extreme value theory).

Gumbel I distributions were fitted to the annual extremes, and 100-year and 1000-year recurrence events were calculated.

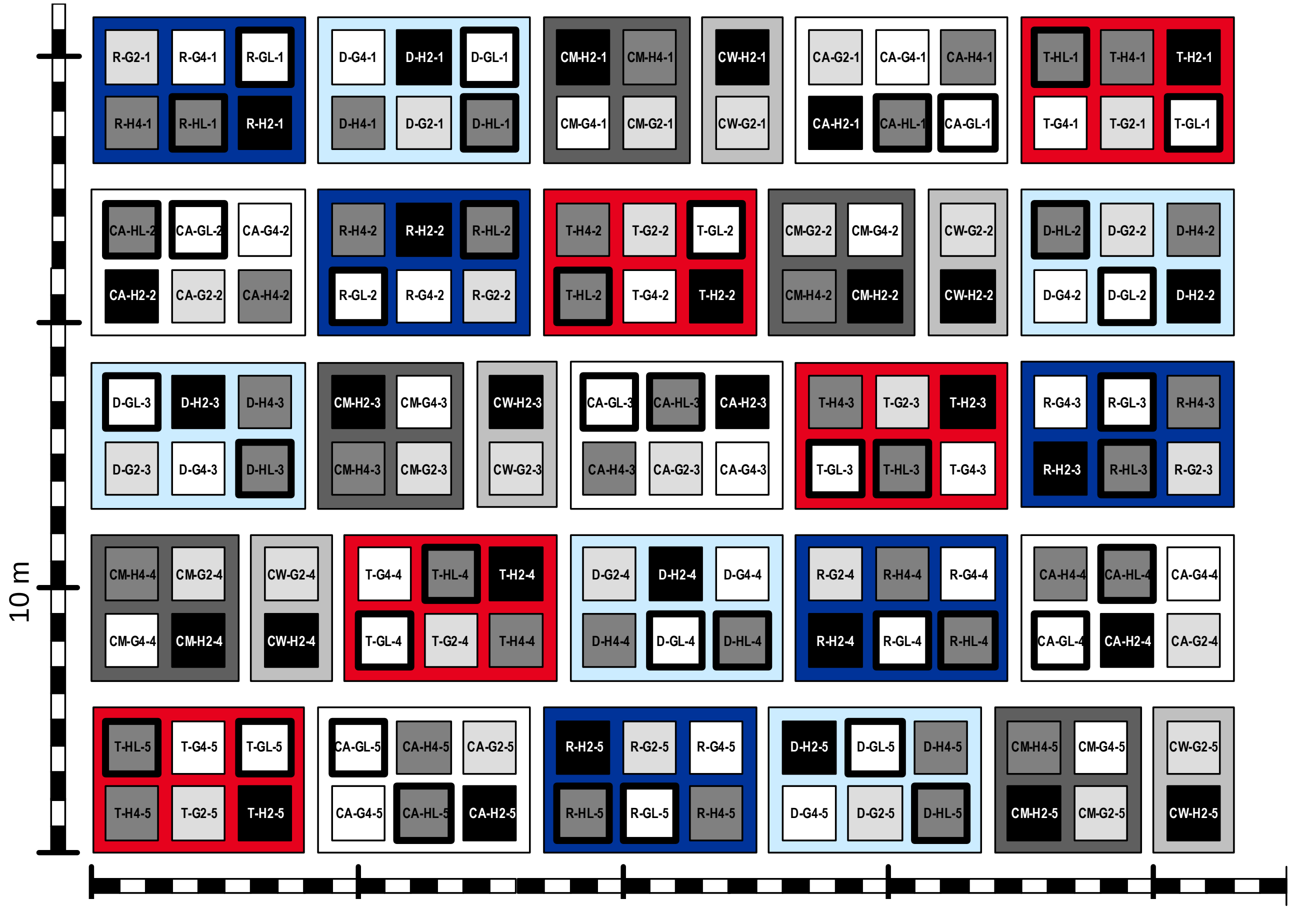
Drought was defined as the number of consecutive days with less than 1 mm daily precipitation.

# *Manipulating precipitation regime*

Drought / heavy rain: local 100-yr / 1000-yr events
Constructed ecosystems: grassland / shrubland
10 common European plant species: forbs/grasses/shrubs/legumes

Drought: 32/42 days    Heavy rain: 170/260 mm in 2 W
2 Controls: ambient conditions + weekly average precipitation

# EVENT I: since 2005, sandy loam




## 5 precipitation regimes

- **CA** Control A (natural weather conditions)
- **CM** Control B (30-year average precipitation)
- **CW** Control C (heating wires without heating
- **R** Intense Rain (Irrigation)
- **D** Drought (rain-out shelters)
- **T** Winter-Warming (heating wires in the soil)

## 6 biodiversity levels

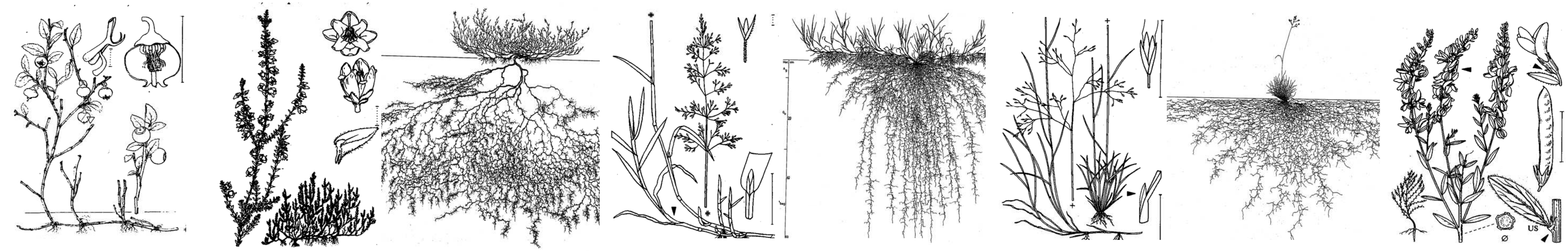
- **G4** Grassland (Grasses & Forbs)
- **G2** Grassland (only grasses)
- **H4** Heath (dwarf shrubs & grasses)
- **H2** Heath (only dwarf shrubs)
- **GL** Grassland with
- **HL** Heath with legu

n = 5,
150 plots

# *Constructed grassland and shrubland*

Arrhenatherum elatius Holcus lanatus Planatgo lanceolata Geranium pratense Lotus corn.

| Abbreviation | Vegetation type | Diversity level | Description | Species |
|---|---|---|---|---|
| $G2^-$ | grassland | $2^-$ | two species, one functional group (grass) | *Arrhenatherum elatius, Holcus lanatus* |
| $G4^-$ | grassland | $4^-$ | four species, two functional groups (grass, herb) | *Arrhenatherum elatius, Holcus lanatus, Plantago lanceolata, Geranium pratense* |
| $G4^+$ | grassland | $4^+$ | four species, three functional groups (grass, herb, legume herb) | *Arrhenatherum elatius, Holcus lanatus, Plantago lanceolata, Lotus corniculatus* |
| $H2^-$ | shrubland | $2^-$ | two species, one functional group (dwarf shrub) | *Calluna vulgaris, Vaccinium myrtillus* |
| $H4^-$ | shrubland | $4^-$ | four species, two functional groups (dwarf shrub, grass) | *Calluna vulgaris, Vaccinium myrtillus, Agrostis stolonifera, Deschampsia flexuosa* |
| $H4^+$ | shrubland | $4^+$ | four species, three functional groups (dwarf shrub, legume shrub, grass) | *Genista tinctoria, Vaccinium myrtillus, Agrostis stolonifera, Deschampsia flexuosa* |



Vaccinium myr. Calluna vulgaris Agrostis stolonifera Deschampsia flexuosa Genista tin.

# *Manipulations*

Drought / heavy rain: local 100-yr / 1000-yr events

Constructed ecosystems: grassland / shrubland

10 common European plant species: forbs/grasses/shrubs/legumes

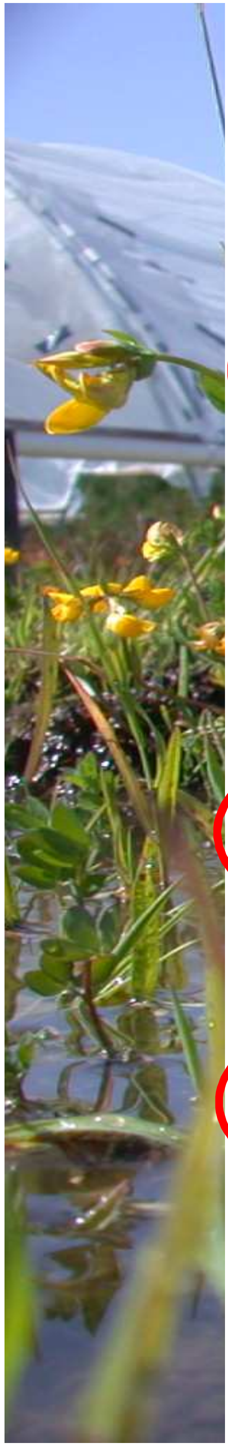
**Drought:** 32/42 days **Heavy rain:** 170/260 mm in 2 W

**2 Controls:** ambient conditions + weekly average precipitation

# *Research Question*

**Effects** of **altered precipitation regimes** on plant species and ecosystem functions

1. primary production
2. water regulation
3. carbon fixation
4. nutrient cycling
5. community stability



# Response Parameter

EVENT

| Ecosystem service | Ecosystem property |
|---|---|
| Primary production | Aboveground net primary production |
| | Nitrogen fixing plants |
| | Plant cover |
| | Below ground biomass |
| | Shoot/ root ratio |
| Water regulation | Soil moisture |
| | Leaf water potential |
| | Leaf carbon isotope signal |
| Carbon fixation | Efficiency of photosynthetic light conversion |
| | Leaf gas exchange |
| | Soil respiration |
| | Maximum leaf and canopy uptake rates |

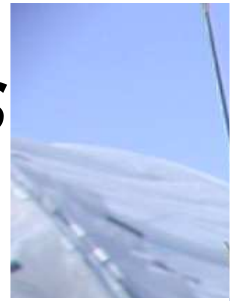
# *Response Parameter*

| Ecosystem service | Ecosystem property |
|---|---|
| Nutrient cycling | Decomposition rate |
| | Mycorrhization rate |
| | Soil microbial biomass |
| | Soil enzyme activity |
| | Plant available soil $NO3^-$ |
| | Plant available soil $NH4^+$ |
| | Soil microbial N |
| | Leaf carbon to nitrogen ratio |
| | Leaf protein content |
| | Leaf carbohydrate content |
| | Leaf nitrogen isotope signal |
| | 1° consumer abundance |

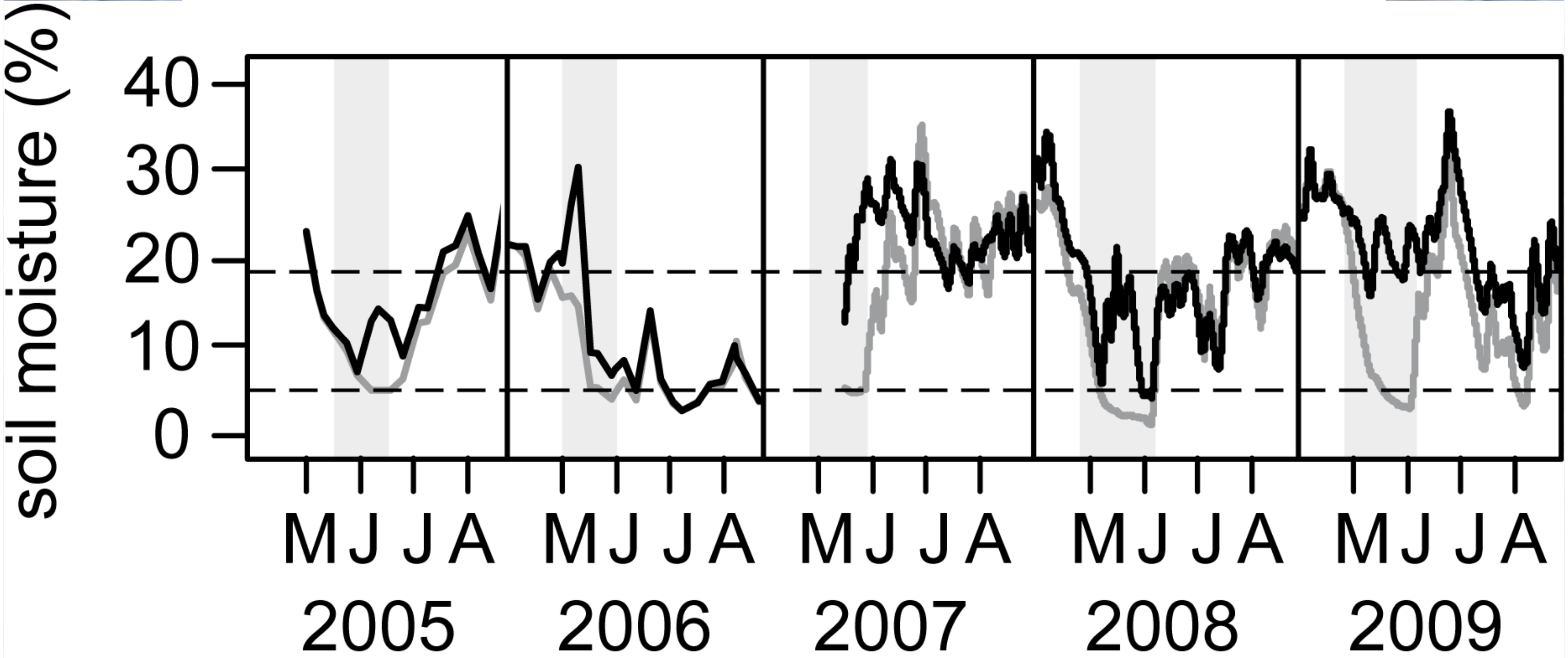
# *Response Parameter*

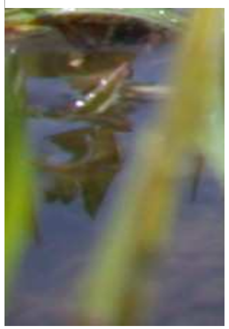
| Ecosystem service | Ecosystem property |
|---|---|
| Compositional stability | Invasibility |
| | Plant compositional change |
| | Competitive effect |
| | Facilitative effect |
| | Senescence |
| | Variability in length of flowering |
| | Variability in flower phenology |
| | Anti-herbivore defense |

# Results

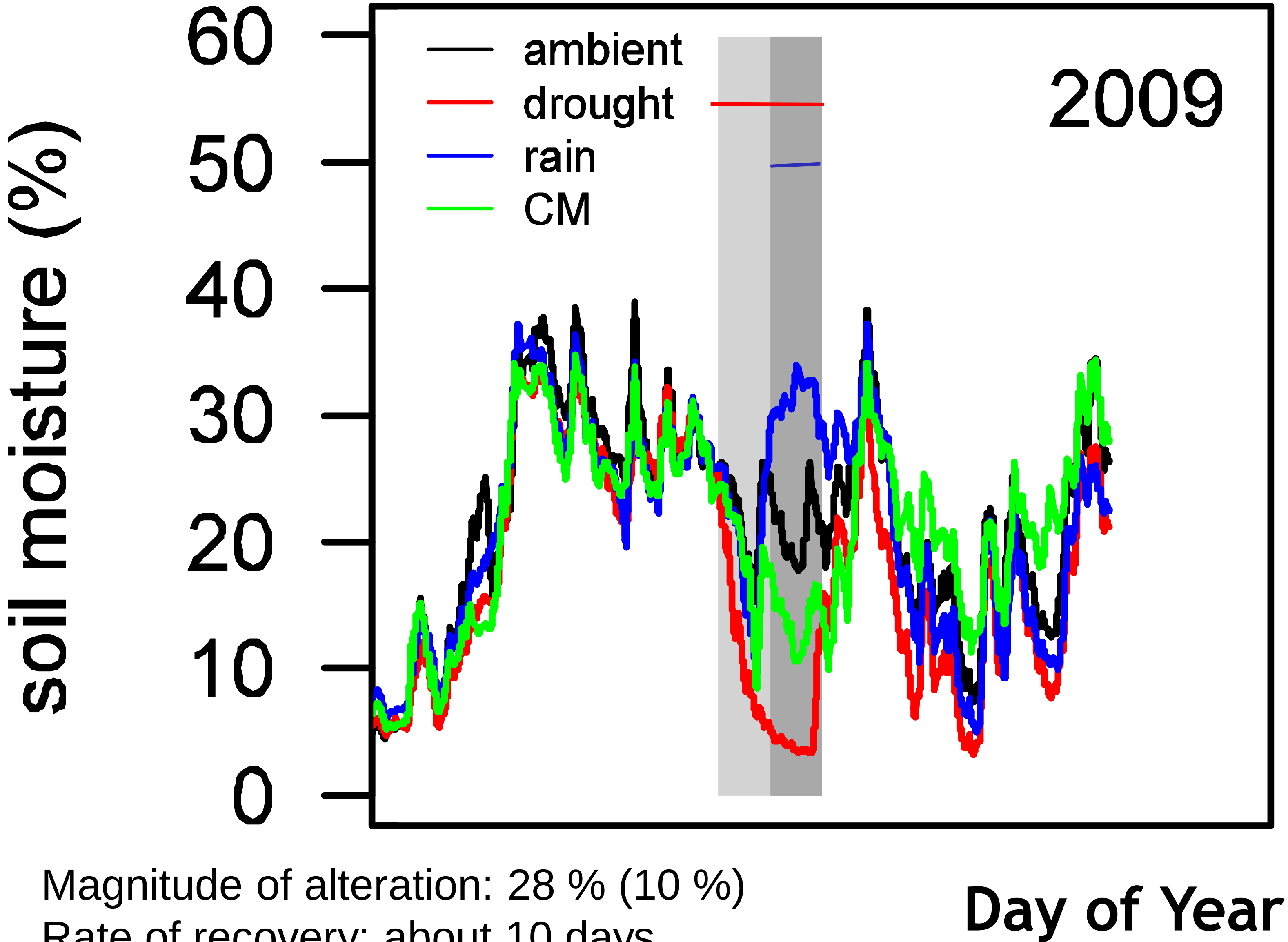
# *Soil moisture effects over 5 years*




*Jentsch et al (accept condit) J Ecol*

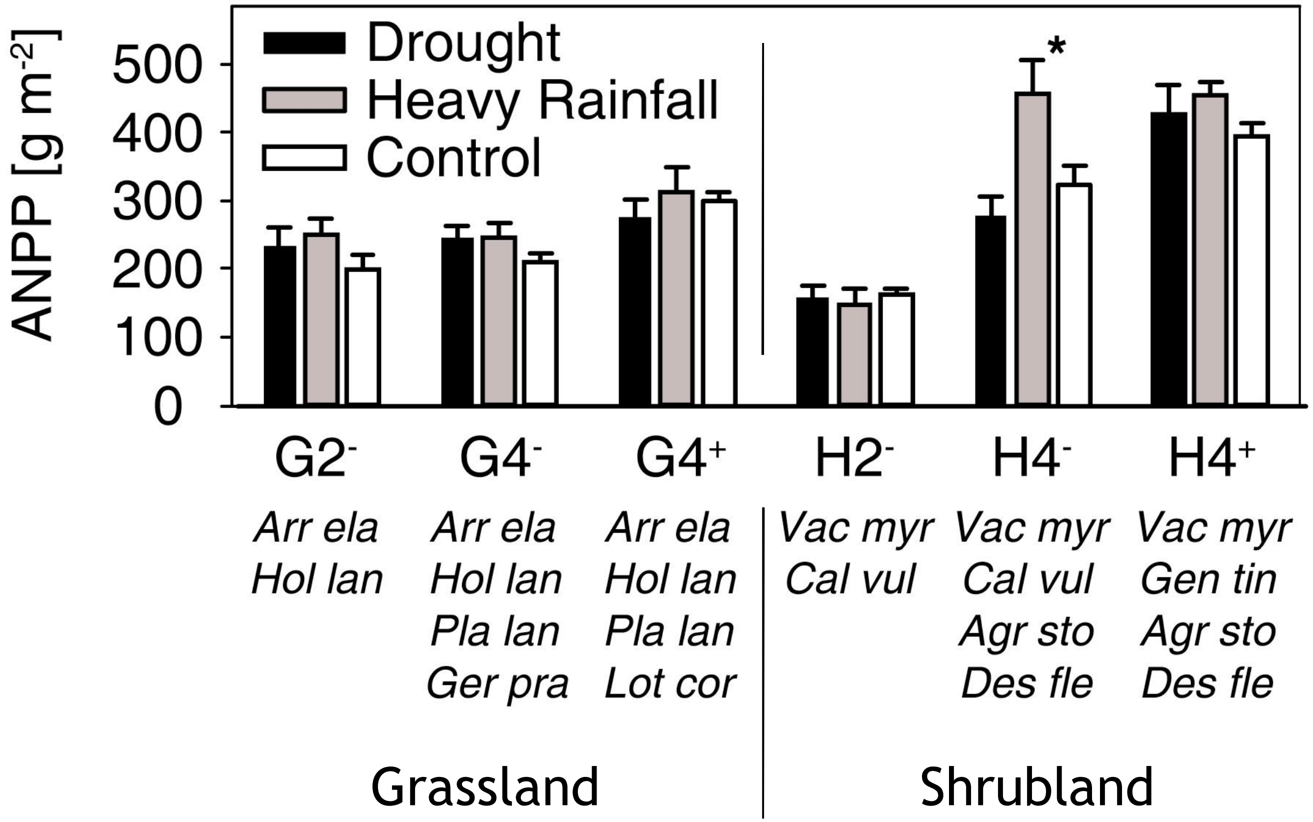
# *Soil moisture*




Magnitude of alteration: 28 % (10 %)
Rate of recovery: about 10 days

# *Productivity - ANPP*

# *Productivity - ANPP*

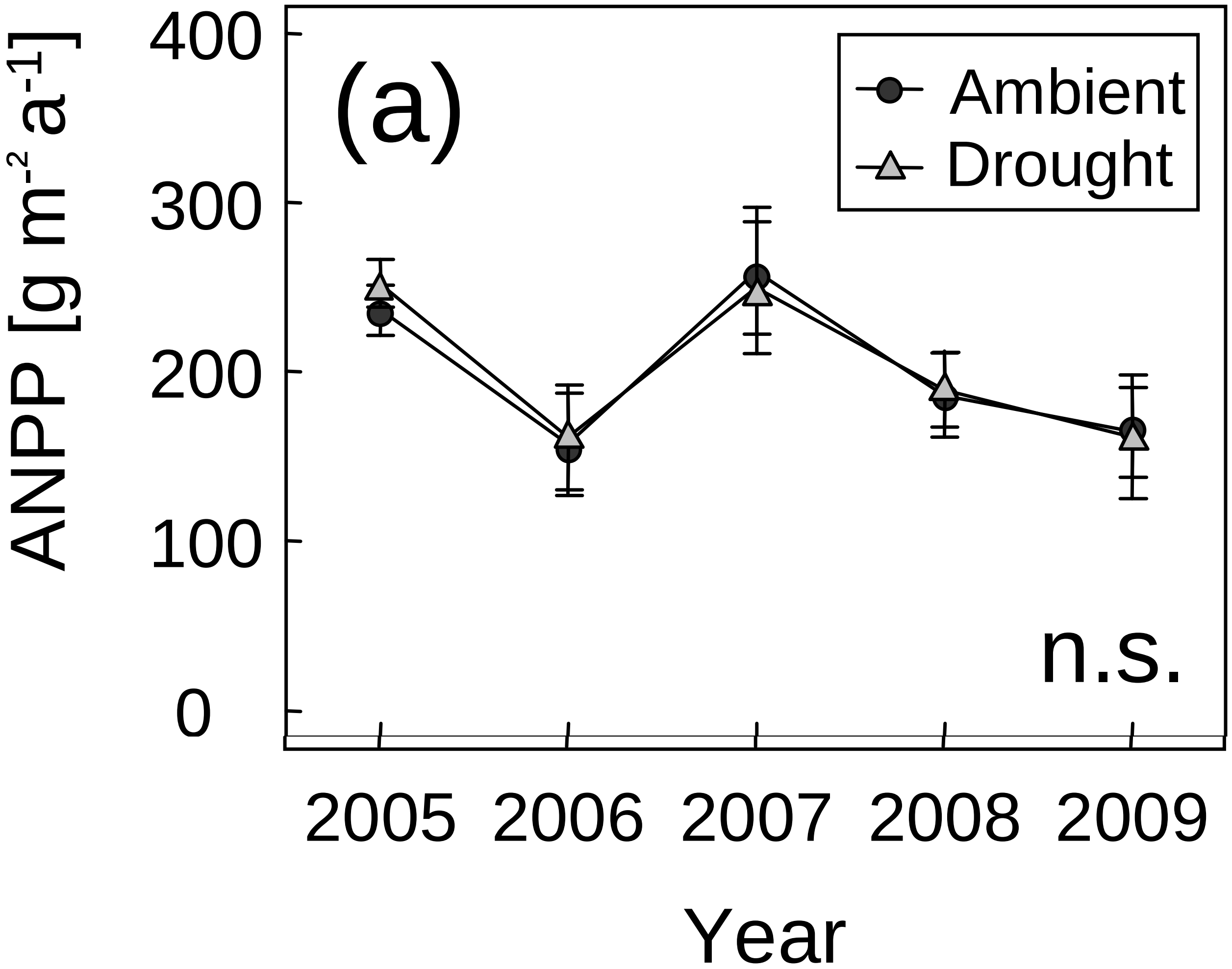



Above ground productivity is very robust in the face of drought and heavy rain (resilient).

Kreyling, Wenigmann, Beierkuhnlein, Jentsch (2008) *Ecosystems*

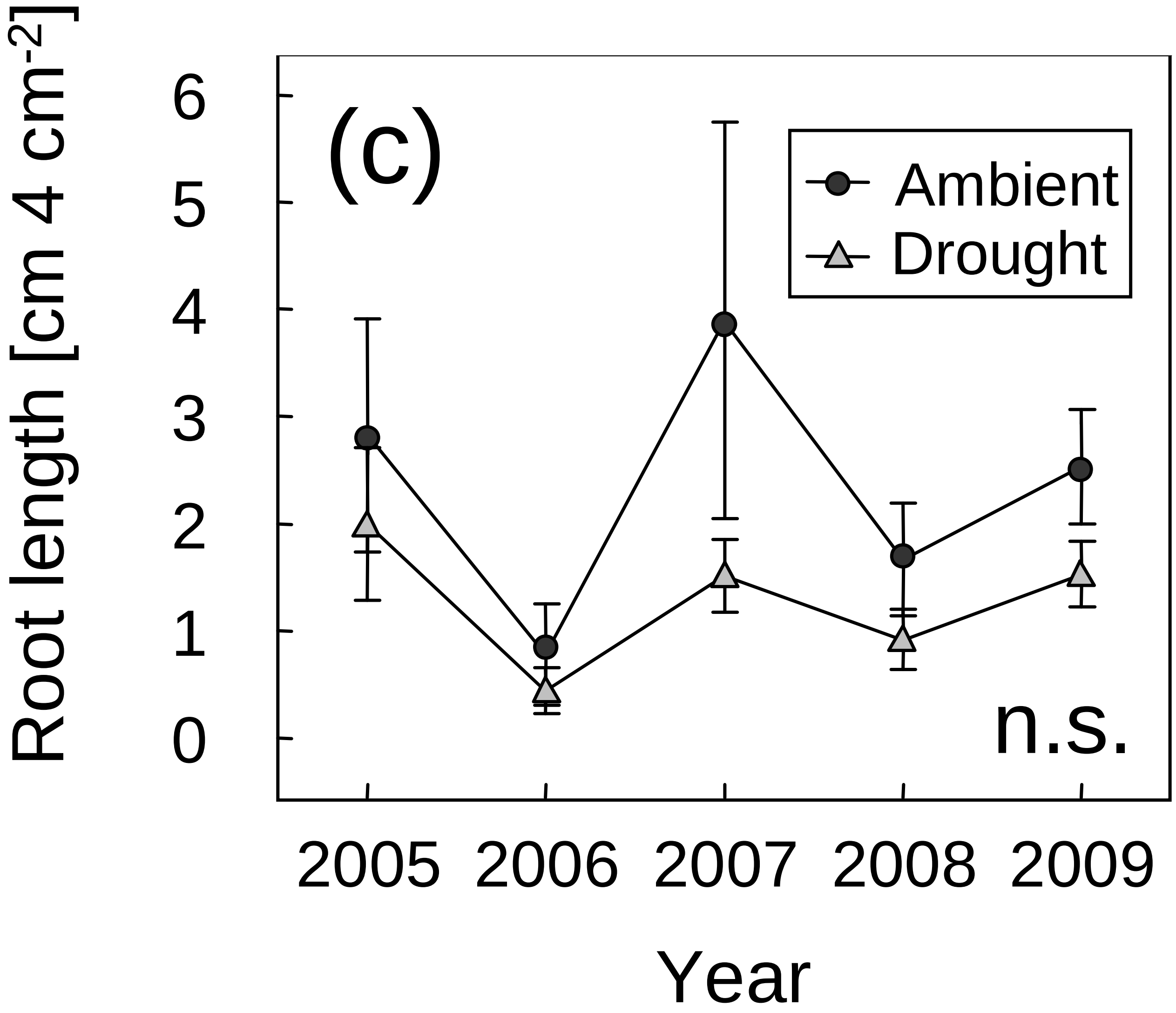
EVENT

# *Drought effects on grassland*



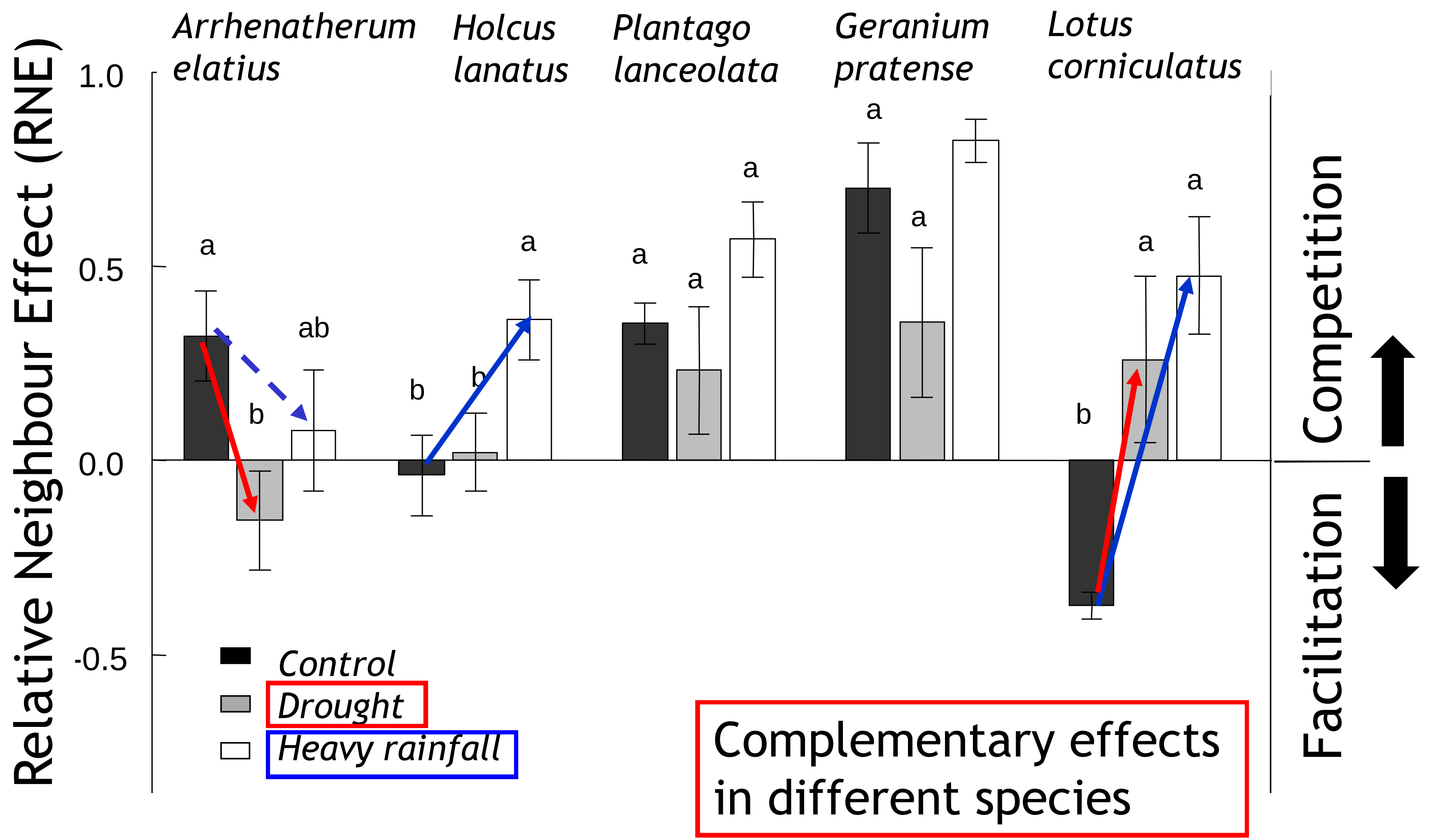

Above ground productivity is very resilient in the face of severe drought in central Europe.

# *Drought effects on grassland*



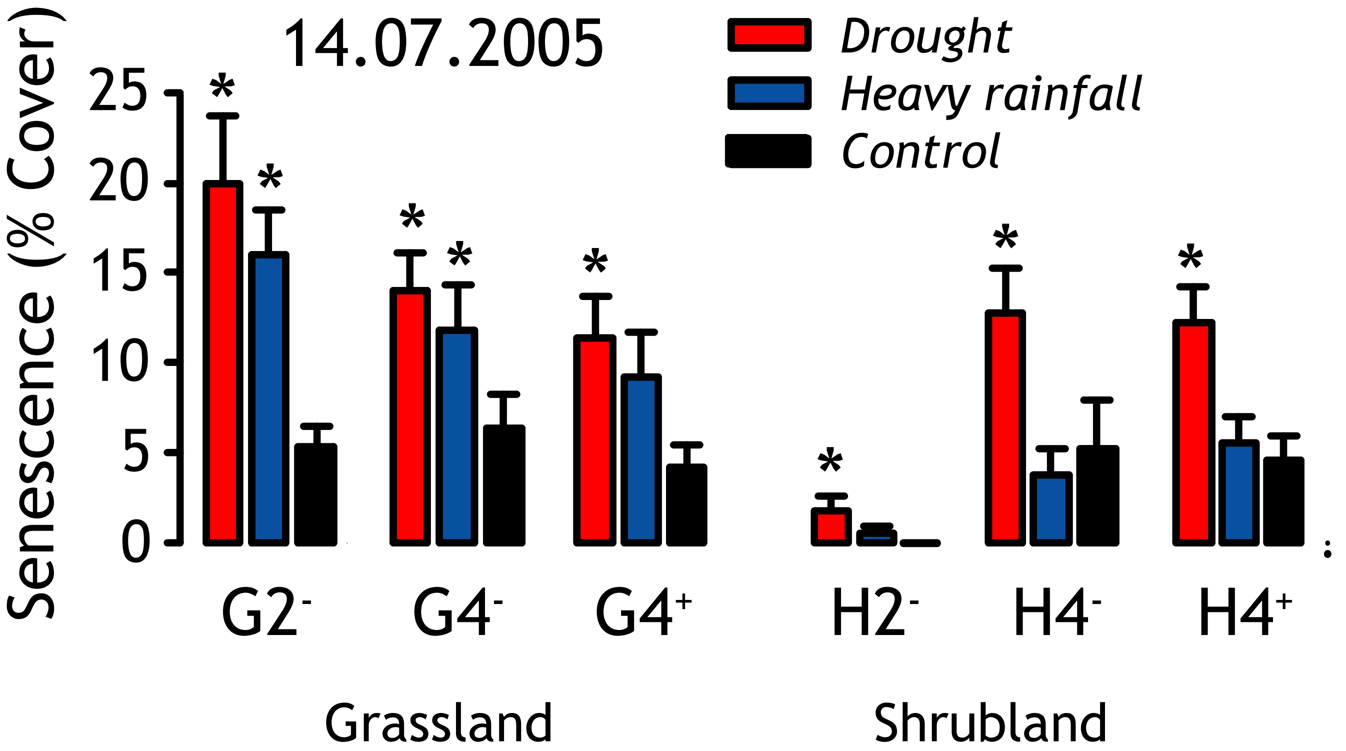

Below ground productivity is very resilient in the face of severe drought in central Europe.

# Competition / Facilitation (RNE)



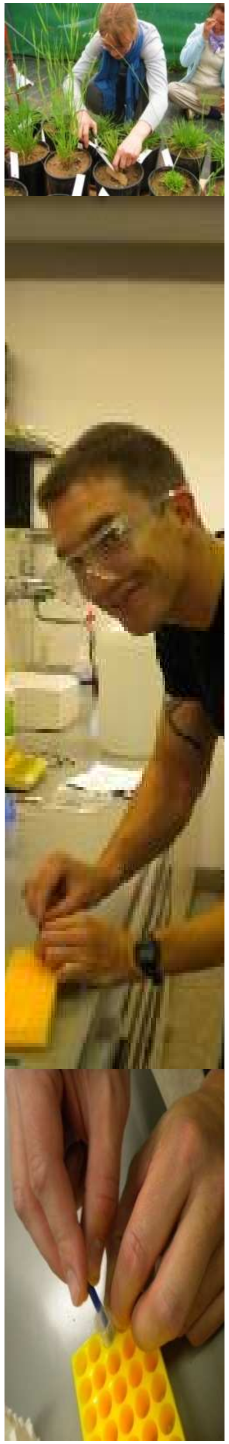

Grant, Beierkuhnlein, Jentsch (in prep.)

# *Senescence*

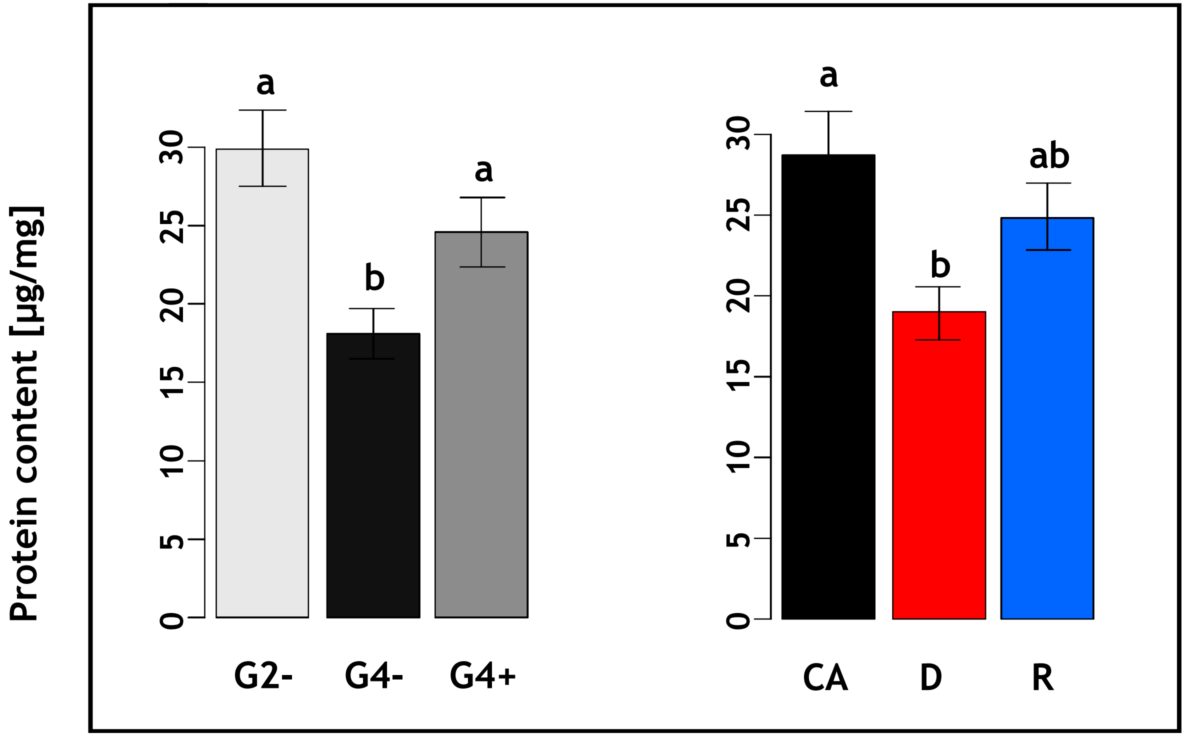



There is a diversity effect in grassland, no legume effect in either ecosystem

Kreyling, Wenigmann, Beierkuhnlein, Jentsch (2008) *Ecosystems*

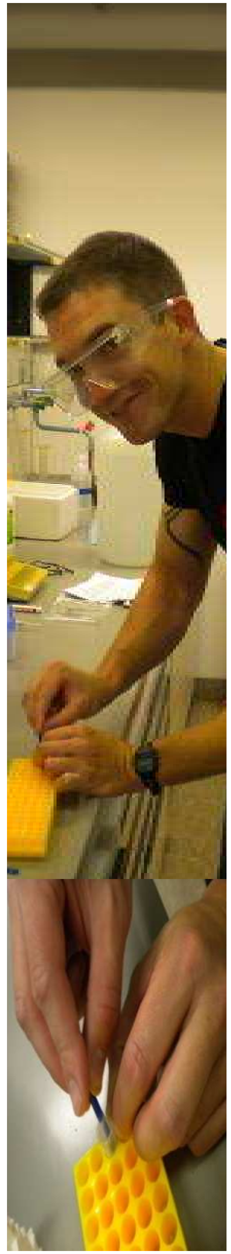


# *Protein content*



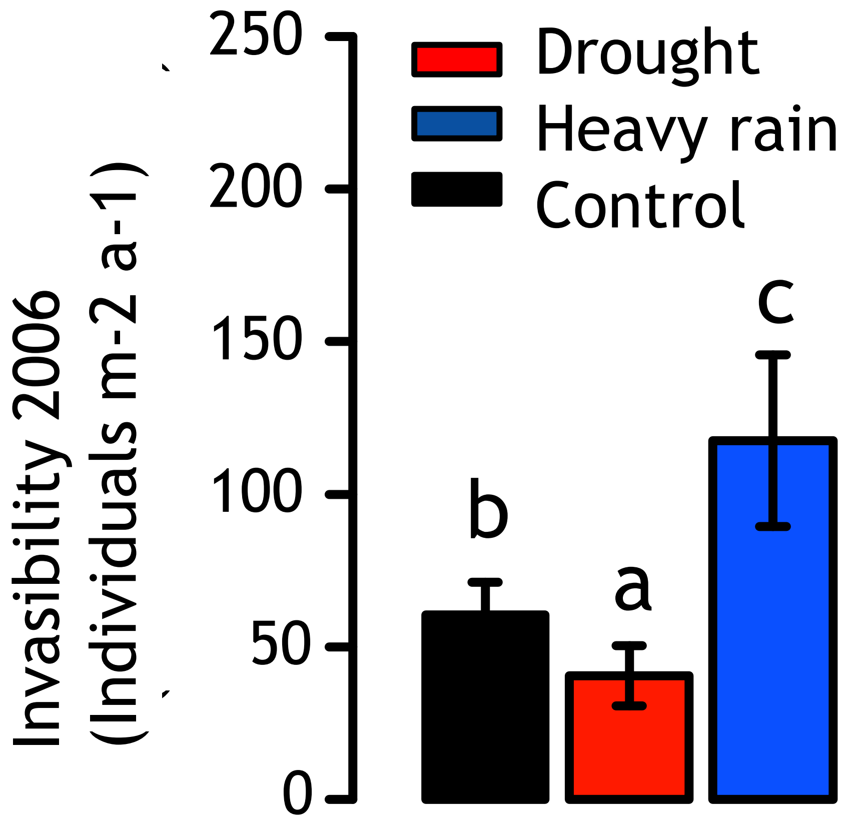

*Holcus lanatus*

Drought reduces leaf protein content (***), free amino acids and N-content (increased C/N ratio). Presence of legumes enhances protein content.



# *Invasibility*

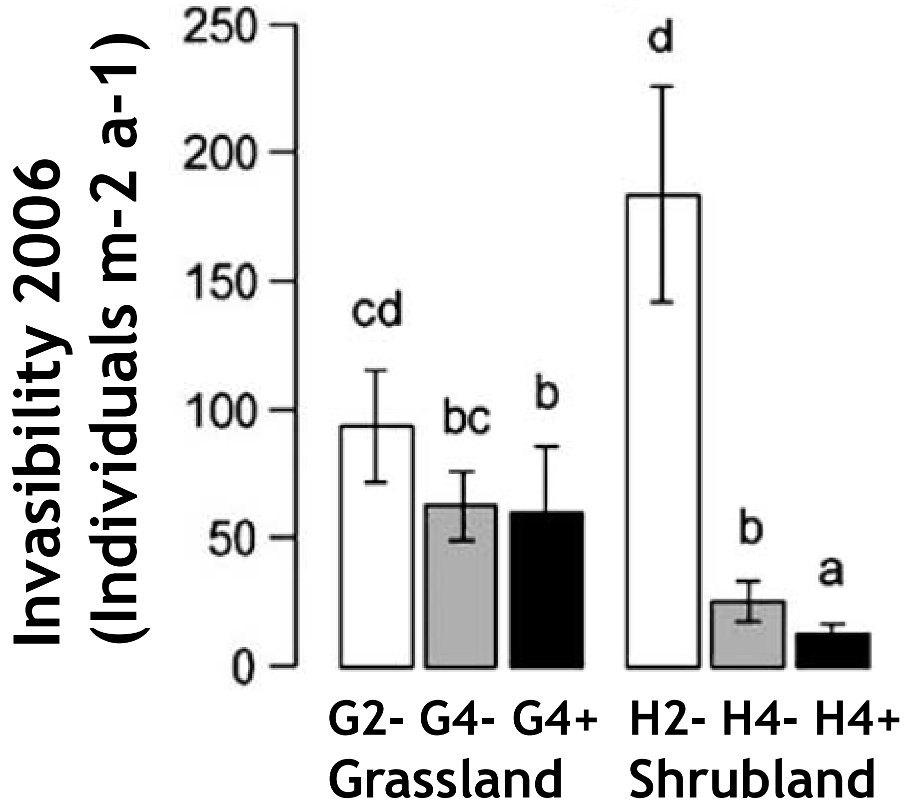
# *Invasibility*




Weather effects despite no change in ANPP:
*Fluctuating Ressources Hypotheses* (Davis et al. 2007)

Kreyling, Beierkuhnlein, Ellis, Jentsch (2008) *Oikos*

# *Invasibility - Diversity*




Diversity reduces invasion despite no change in ANPP: *Diversity Resistance Hypothesis* (Elton 1958) (weather & diversity effects are non-additive)

Kreyling, Beierkuhnlein, Ellis, Jentsch (2008) *Oikos*

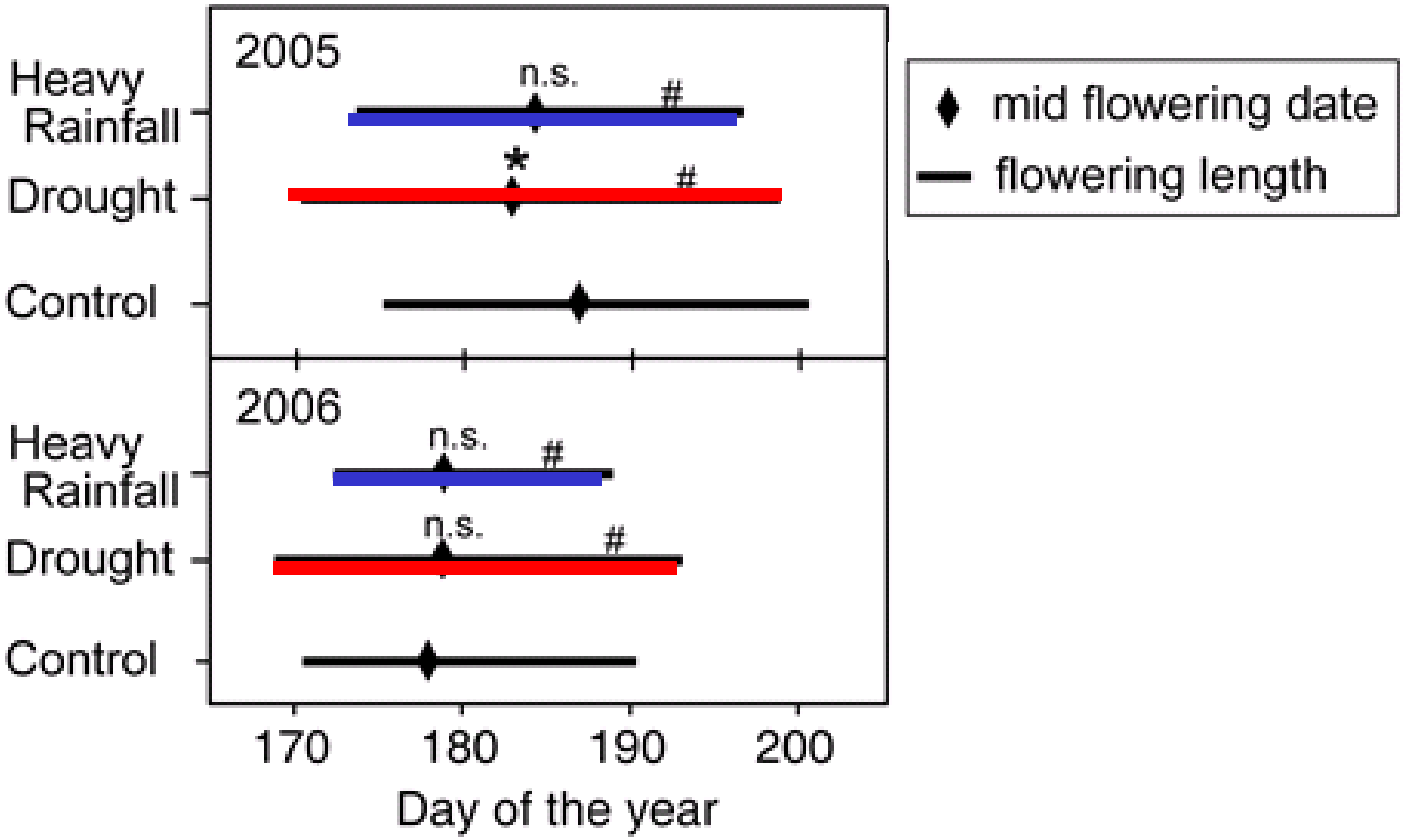
# *Flower phenology*

# *Flower phenology*

Earlier onset of spring in Europe!
For the last 30 years:
2.5 days / decade,
4.6 days/ 1C° temperature increase

Menzel et al. (2006) Global Change Biology

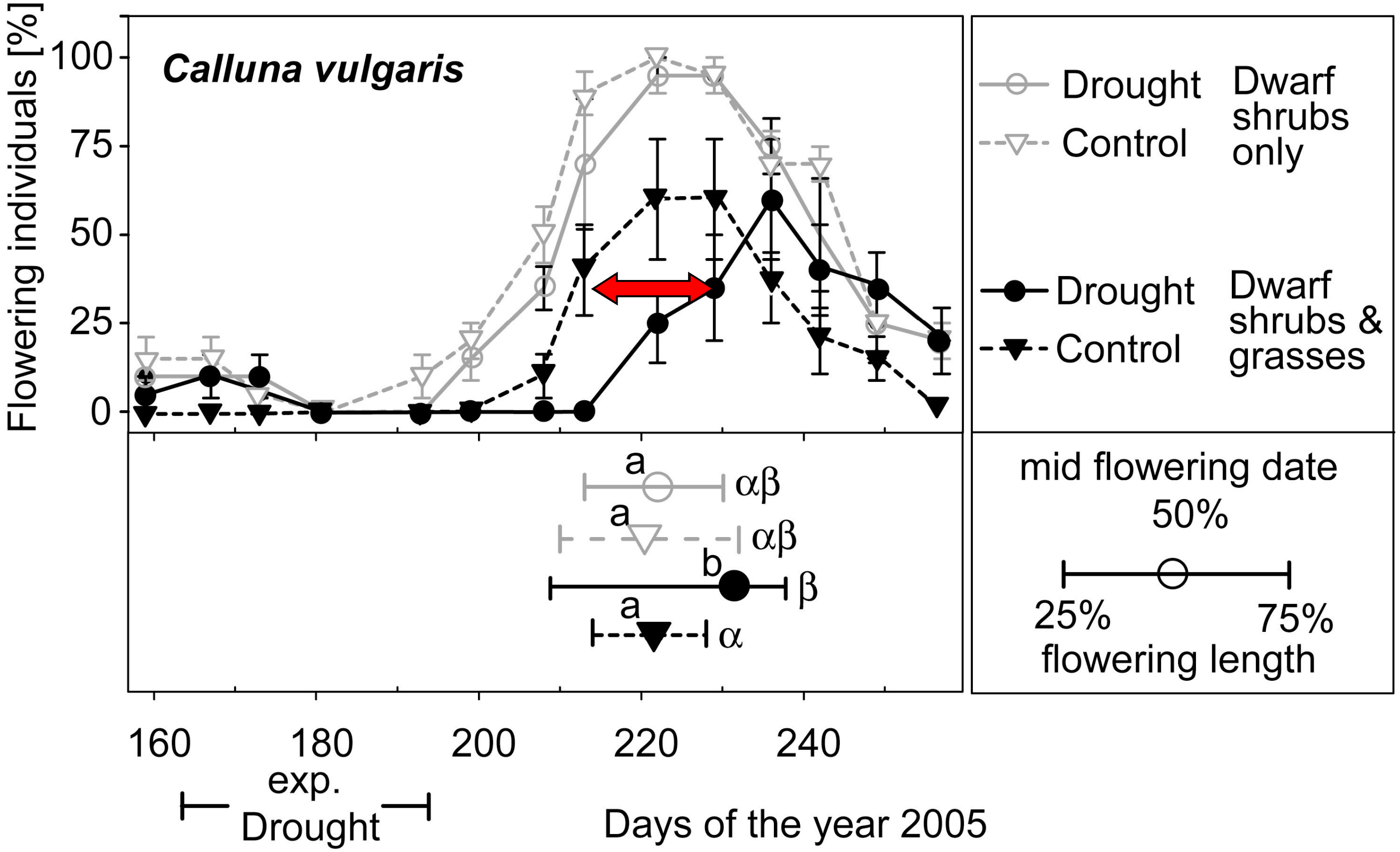
# *Flower phenology*




Drought: Onset of flowering advanced by 4 days
length of flowering period expanded 4 days
Heavy rain: flowering period compressed by 5,4 days

Jentsch, Kreyling, Böttcher, Beierkuhnlein (2008) *Global Change Biology*

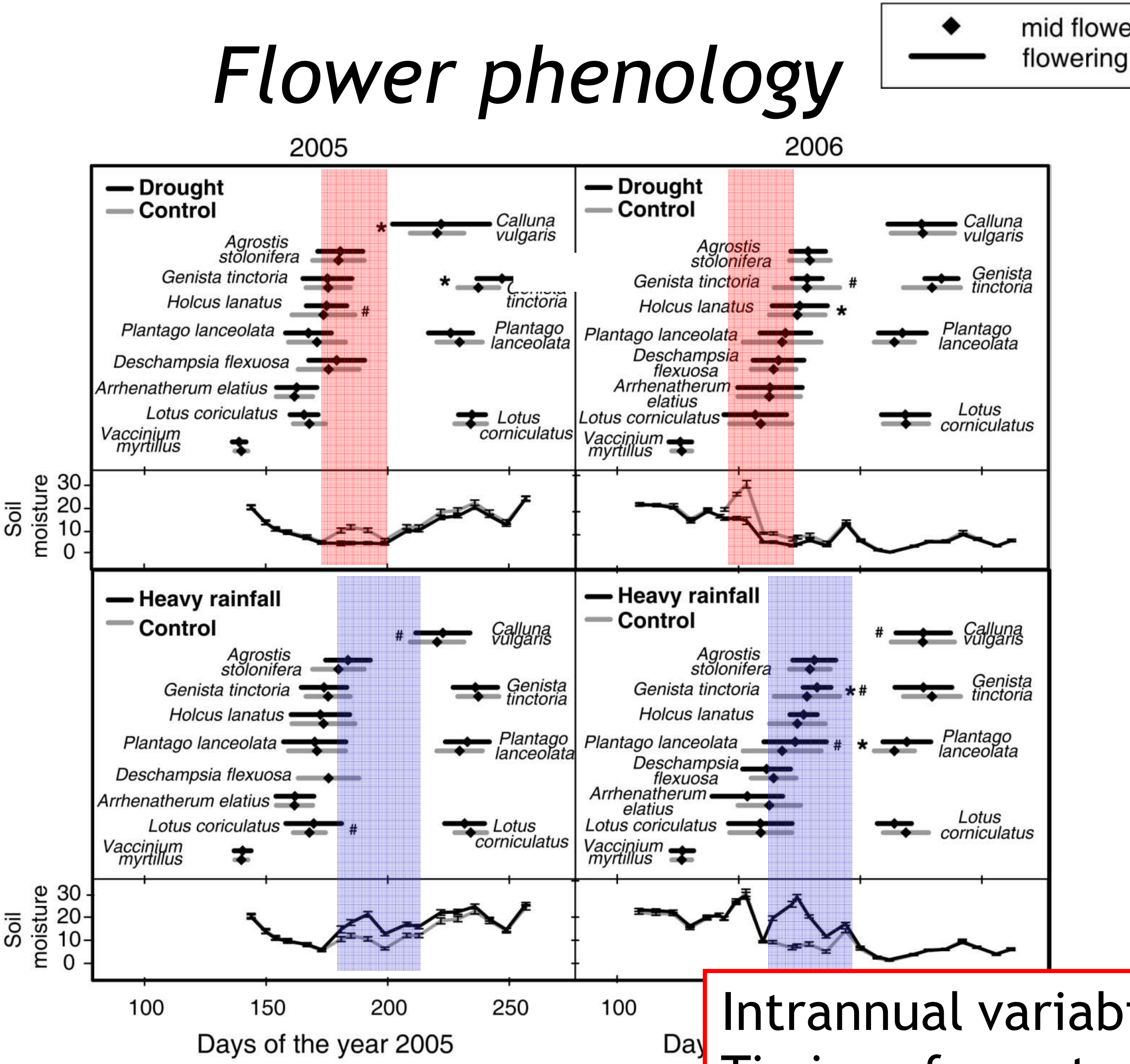
# *Flower phenology*




<u>*Calluna vulg*</u>.: 10 d delayed and 22 d elongated after drought (grwon in mixture with *Deschampsia*)
<u>*Lotus co*</u>.: 26 d advanced, 37 d compressed after rain
Decoupling of biotic interactions? – Pollination?

Jentsch, Kreyling, Böttcher, Beierkuhnlein (2008) *Global Change Biology*

# *Flower phenology*



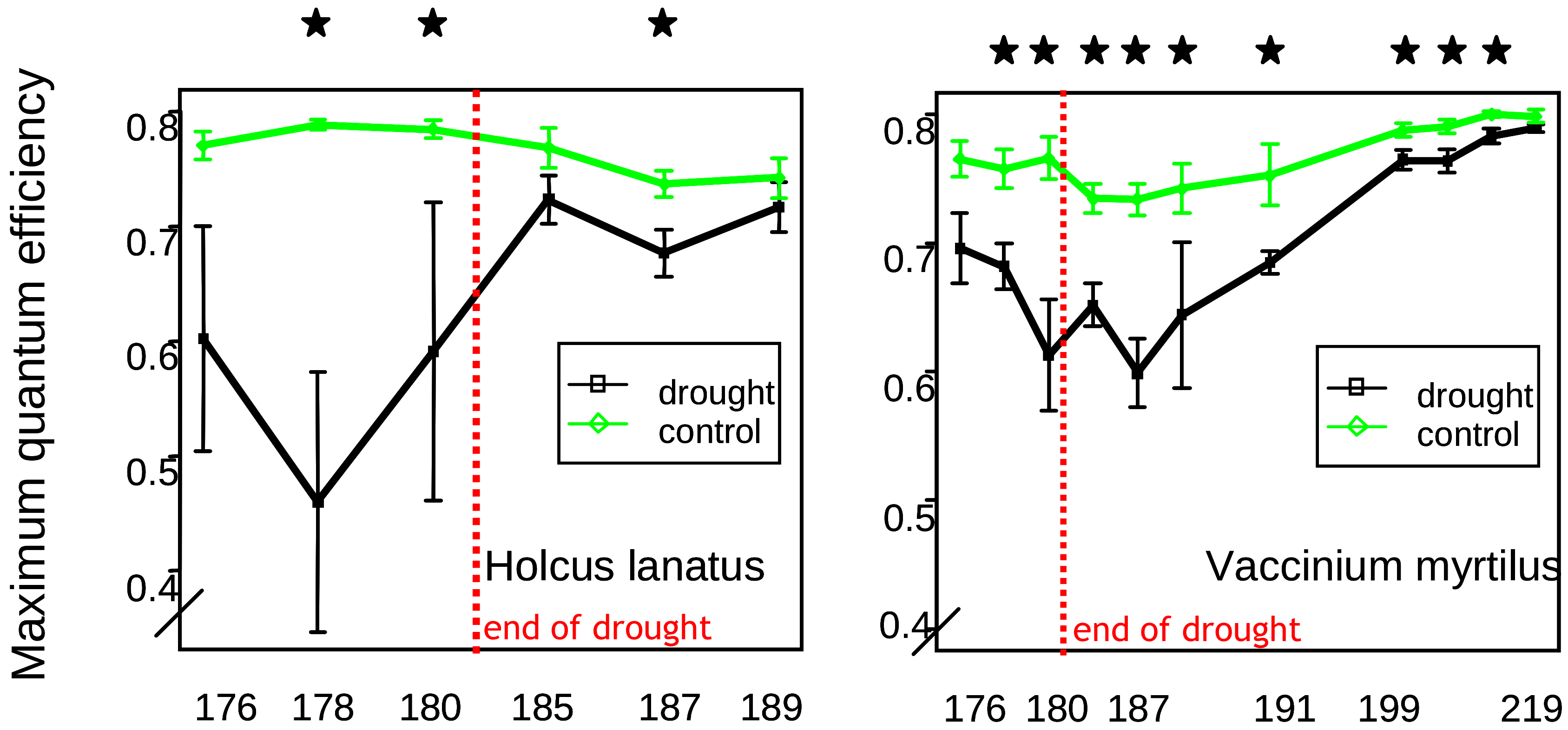

Intrannual variability!
Timing of event crucial

Jentsch, Kreyling, Böttcher, Beierkuhnlein (2008) *Global Change Biology*

# *Photosynthetic Performance*

# *Photosynthetic Performance*

## *Holcus lanatus & Vaccinium myrtillus*

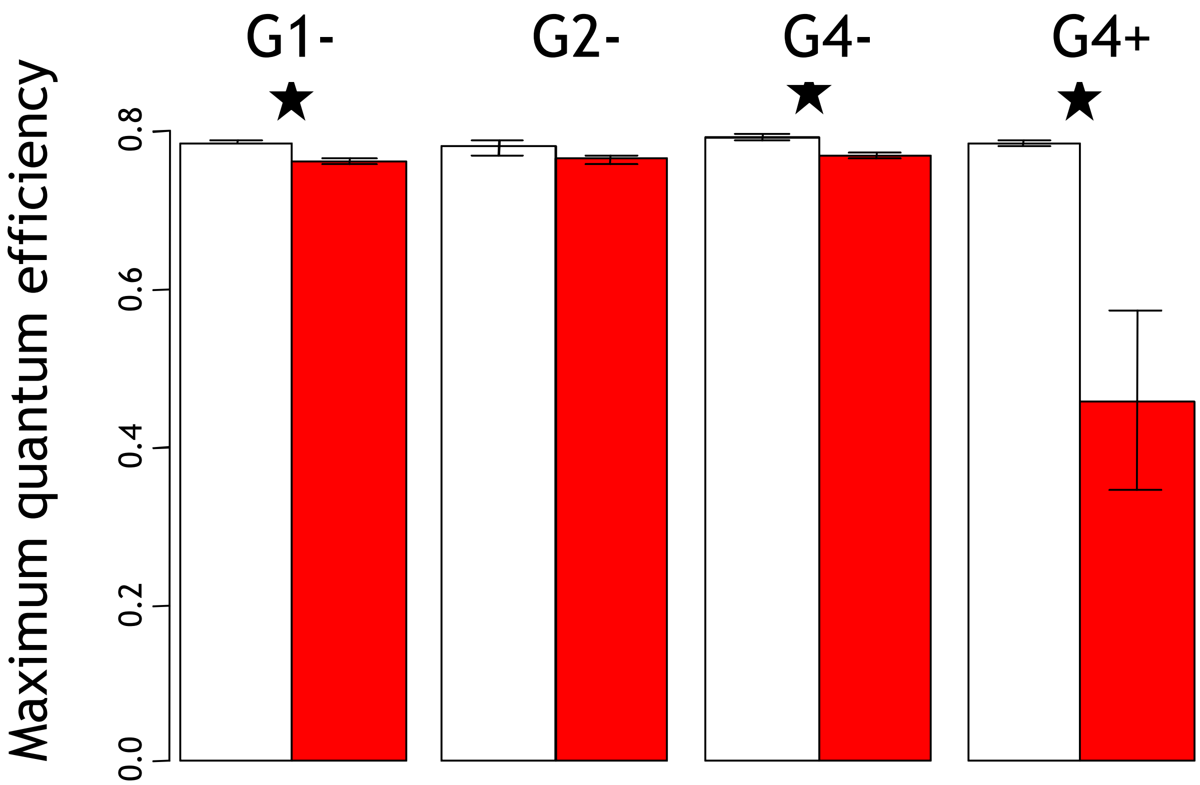



**Magnitude: 63 %**
**Recovery: 7 days**

**Magnitude: 18 %**
**Recovery: 37 days**

Walter, Rascher, Beierkuhnlein, Veste, Märtin, Jentsch (submitted) Funct Ecol

# *Maximum Quantum Efficiency Holcus lanatus*




control
drought

*Legume presence enhances stress level in target grass*

Walter, Rascher, Veste, Beierkuhnlein, Jentsch (in prep.)

# *Trophic Interactions*

*Insect herbivory*
*Decomposition rate (cellulose)*
*Microbial enzymatic activity*
*Microbial community composition*

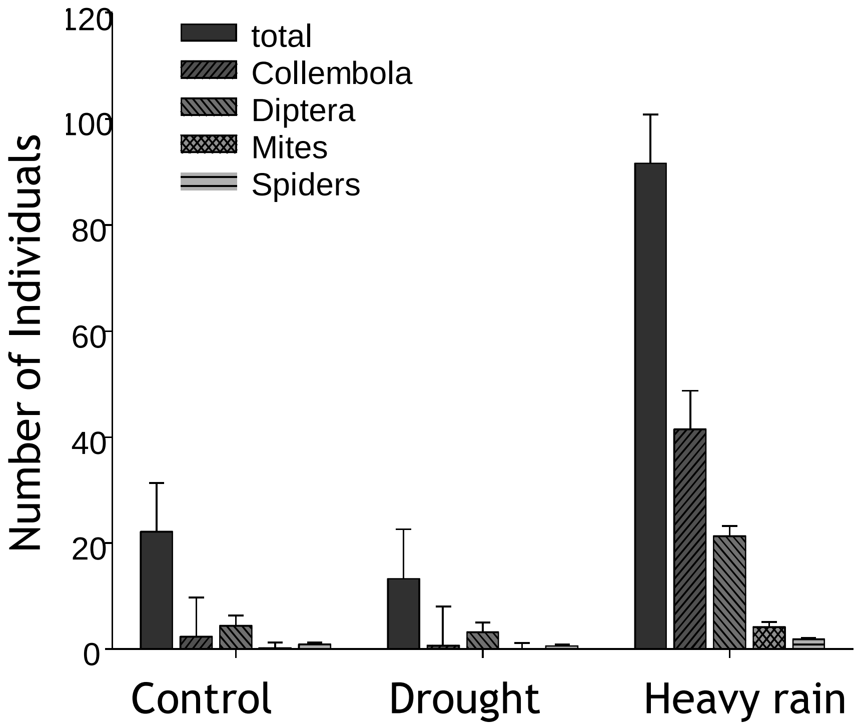
# *Herbivory*

Plant stress hypothesis
(White 1984)

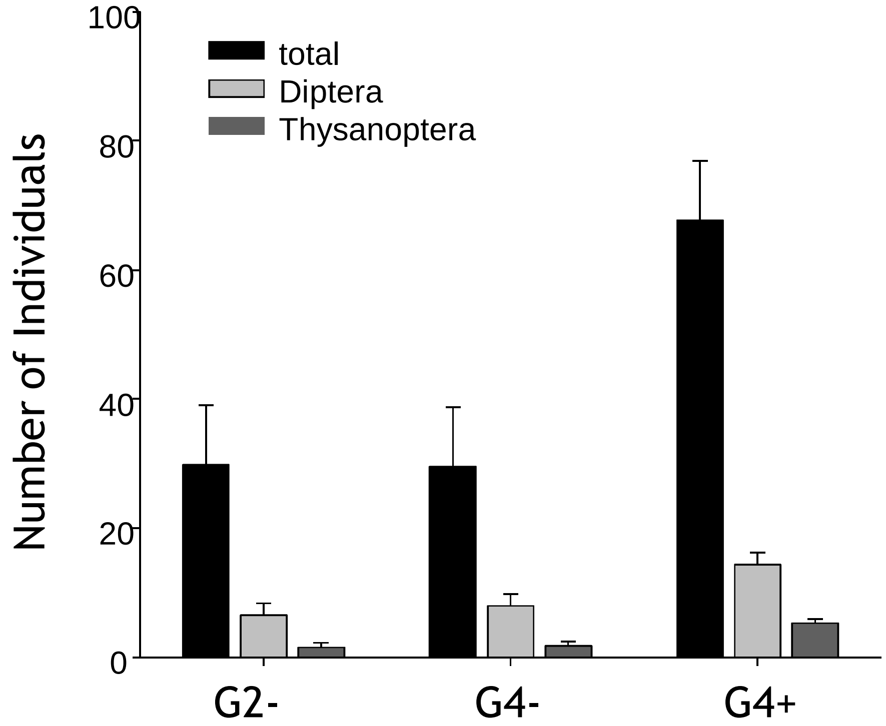
Plant vigour hypothesis
(Price 1991)

# *Herbivory*

## Extreme Weather Events




## Diversity

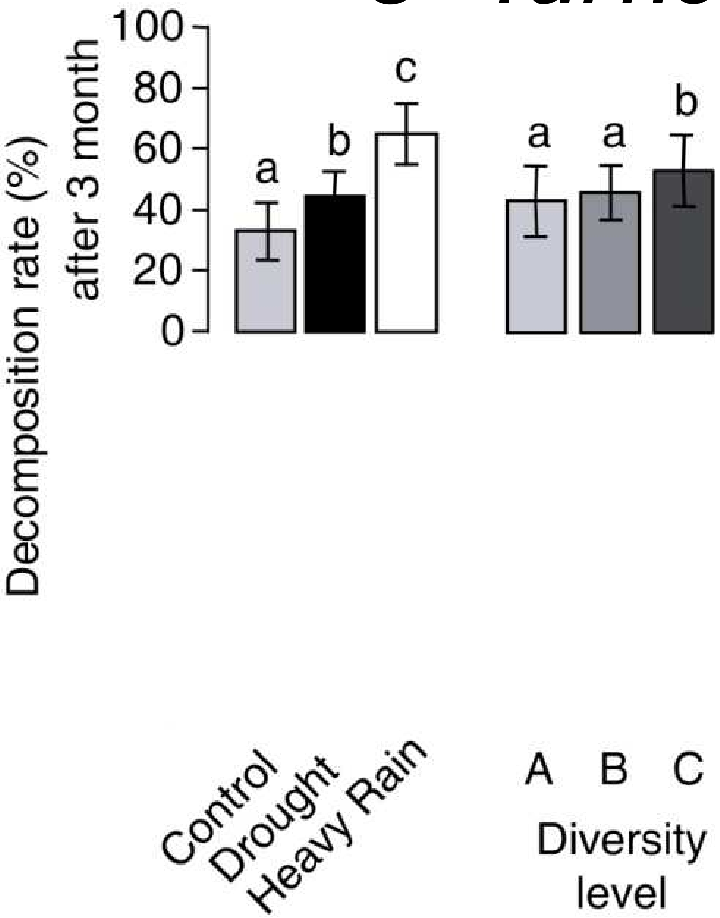



Plant stress hypothesis
(White 1984)

Plant vigour hypothesis
(Price 1991)

# *Decomposition Rate (Cellulose) C- Turnover*

EVENT

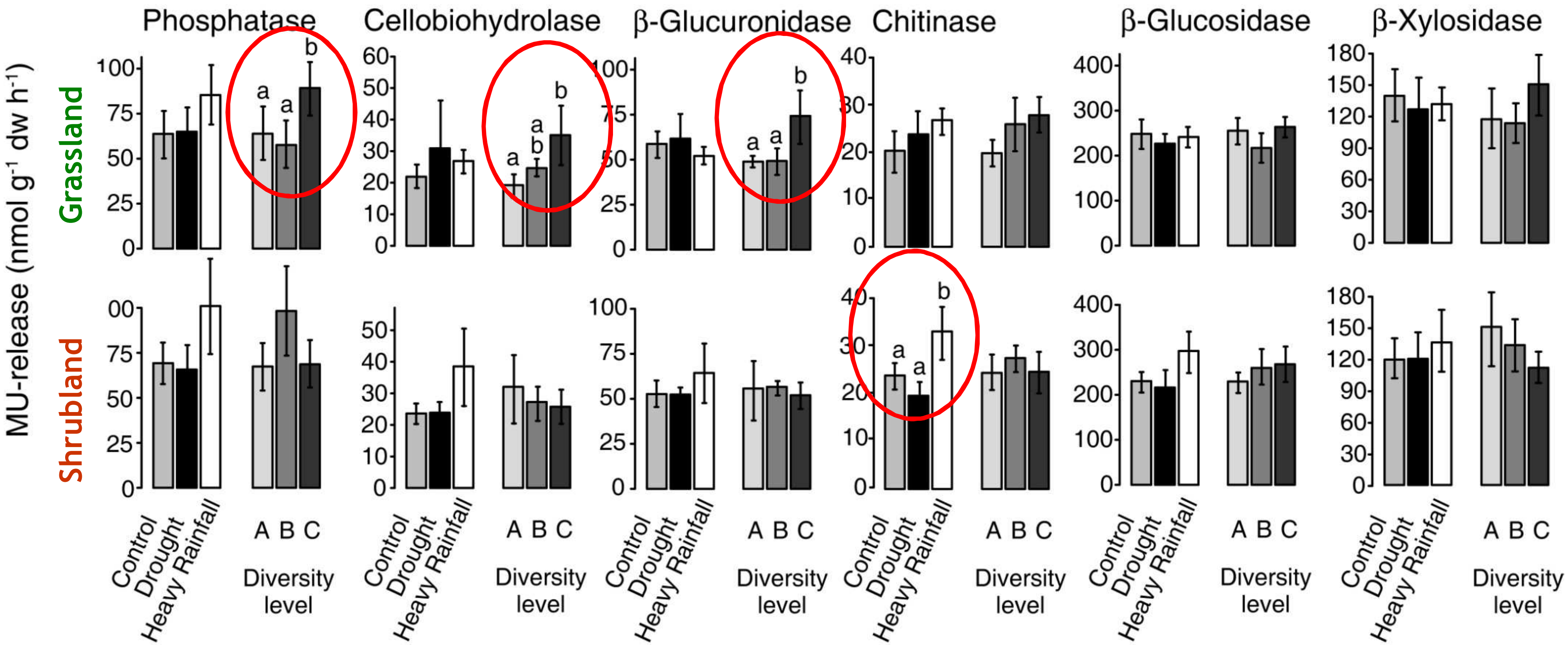



| ANOVA | F | p |
|---|---|---|
| weather | 92.4 | < 0.001 |
| div | 7.0 | < 0.001 |

*Drought, heavy rain and species diversity enhance decomposition rate for 3-6 month*

**Kreyling, Beierkuhnlein, Elmer, Pritsch, Wöllecke, Schloter, Jentsch (2008)** ***Plant and Soil***

# *Microbial Enzymatic Activity*




*No drought effect on any enzyme activity*
*Heavy rain increased only chitinase in shrubland*
*(degrades chitin from fungi or athropods)*
*Diversity increased only phosphatase (cleaves organically bound phosphate) and cellobiohydrolase (degrades plant cell wall components) in grassland*

**Kreyling, Beierkuhnlein, Elmer, Pritsch, Wöllecke, Schloter, Jentsch (2008) *Plant and Soil***

# Summary: drought effects on grassland

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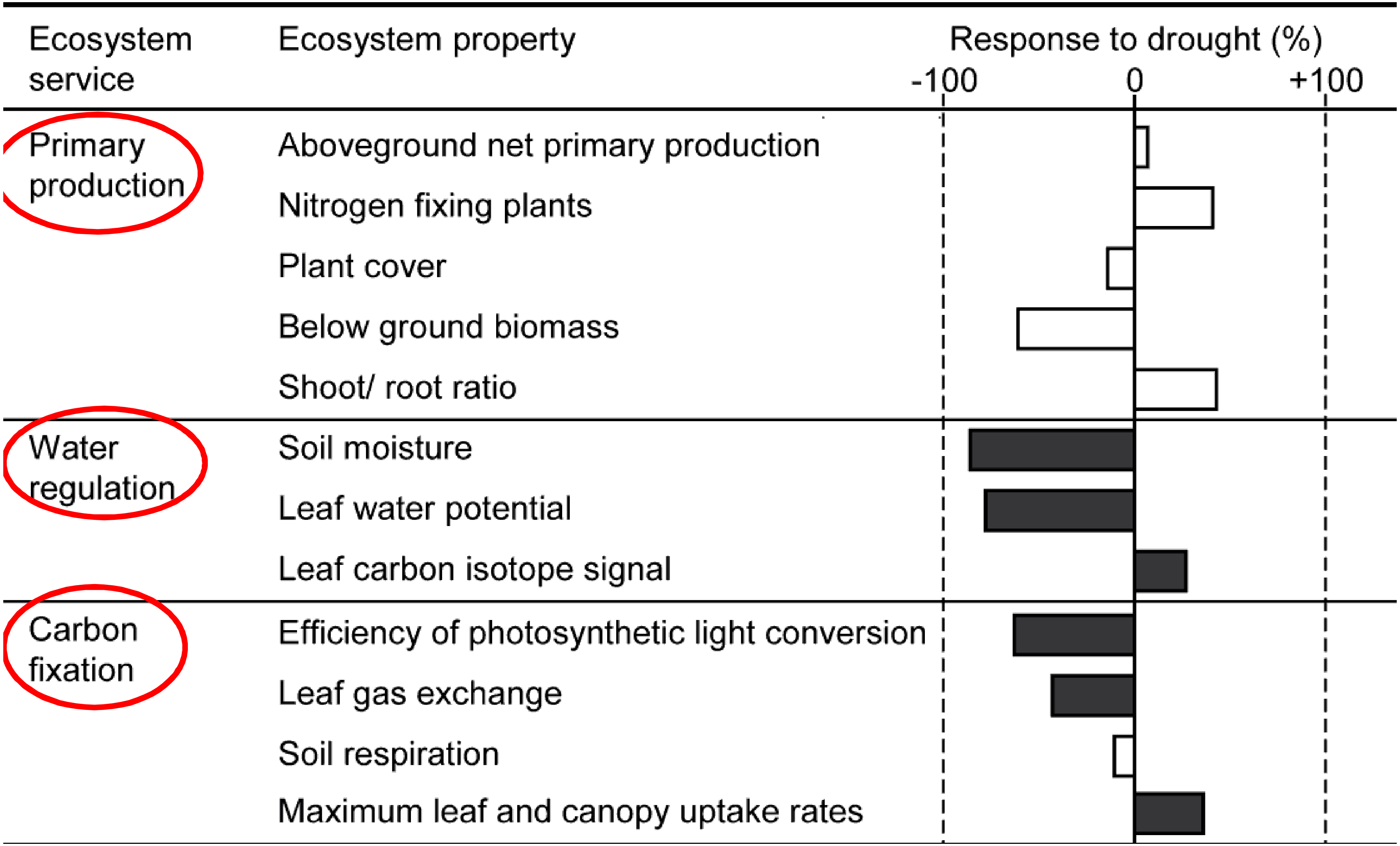
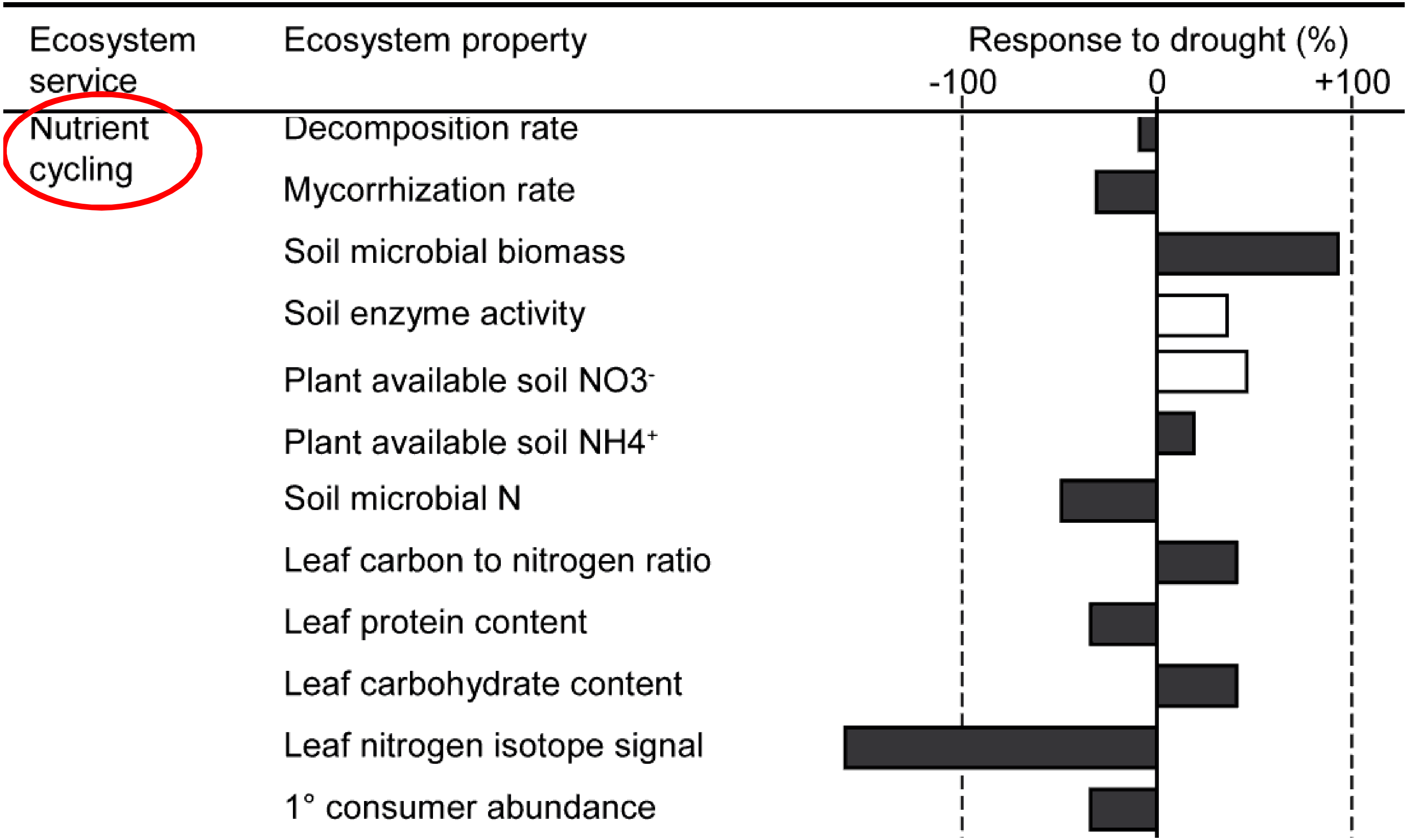



*Jentsch et al (accept condit) J Ecol*

# Summary: drought effects on grassland

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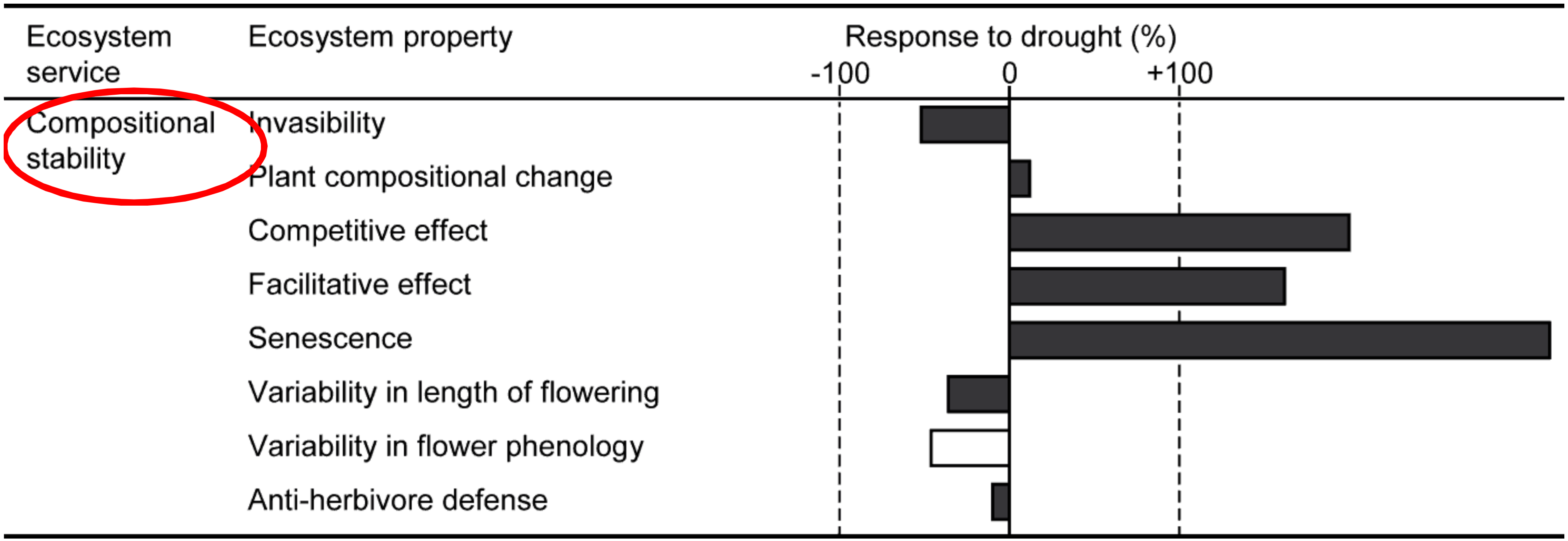
# Summary: drought effects on grassland




*Jentsch et al (accept condit) J Ecol*

# *Conlcusion*

Extreme weather events
stimulate
plant regulating functions

while maintaining stability
in primary productivity!

# *Research Frontiers*

Underlying mechanism, esp. temporal hierachy of response and recovery rates to extreme weather events ?

Effects of timing of events (seasonality) more important for organisms and ecosystem functions than magnitude and frequency ?

Role of biodiversity in buffering effects of extreme weather events ?

2011: Extremeness? Who dies first?

Conservation Biology

*Essay*

# One Hundred Questions of Importance to the Conservation of Global Biological Diversity

W. J. SUTHERLAND,[1] W. M. ADAMS,[2] R. B. ARONSON,[3] R. AVELING,[4] T. M. BLACKBURN,[5] S. BROAD,[6] G. CEBALLOS,[7] I. M. CÔTÉ,[8] R. M. COWLING,[9] G. A. B. DA FONSECA,[10] E. DINERSTEIN,[11] P. J. FERRARO,[12] E. FLEISHMAN,[13] C. GASCON,[14] M. HUNTER JR.,[15] J. HUTTON,[16] P. KAREIVA,[17] A. KURIA,[18] D. W. MACDONALD,[19] K. MACKINNON,[20] F. J. MADGWICK,[21] M. B. MASCIA,[22] J. MCNEELY,[23] E. J. MILNER-GULLAND,[24] S. MOON,[25] C. G. MORLEY,[26] S. NELSON,[27] D. OSBORN,[28] M. PAI,[29] E. C. M. PARSONS,[30] L. S. PECK,[31] H. POSSINGHAM,[32] S. V. PRIOR,[1] A. S. PULLIN,[33] M. R. W. RANDS,[34*] J. RANGANATHAN,[35] K. H. REDFORD,[36] J. P. RODRIGUEZ,[37] F. SEYMOUR,[38] J. SOBEL,[39] N. S. SODHI,[40] A. STOTT,[41**] K. VANCE-BORLAND,[42] AND A. R. WATKINSON[43]

„Extreme weather events
are generating global concerns
about the most effective strategies
for conserving biological diversity.“

(Sutherland et al. 2009, Conservation Biology)


Thank You!

Carl Beierkuhnlein

Jürgen Kreyling
Kerstin Grant
Julia Walter
Roman Hein
Laura Nagy

Michael Schloter
Karin Pritsch
Brajesh Singh
Uwe Rascher
Jens Wöllecke

Master students
Student helpers
Technicians

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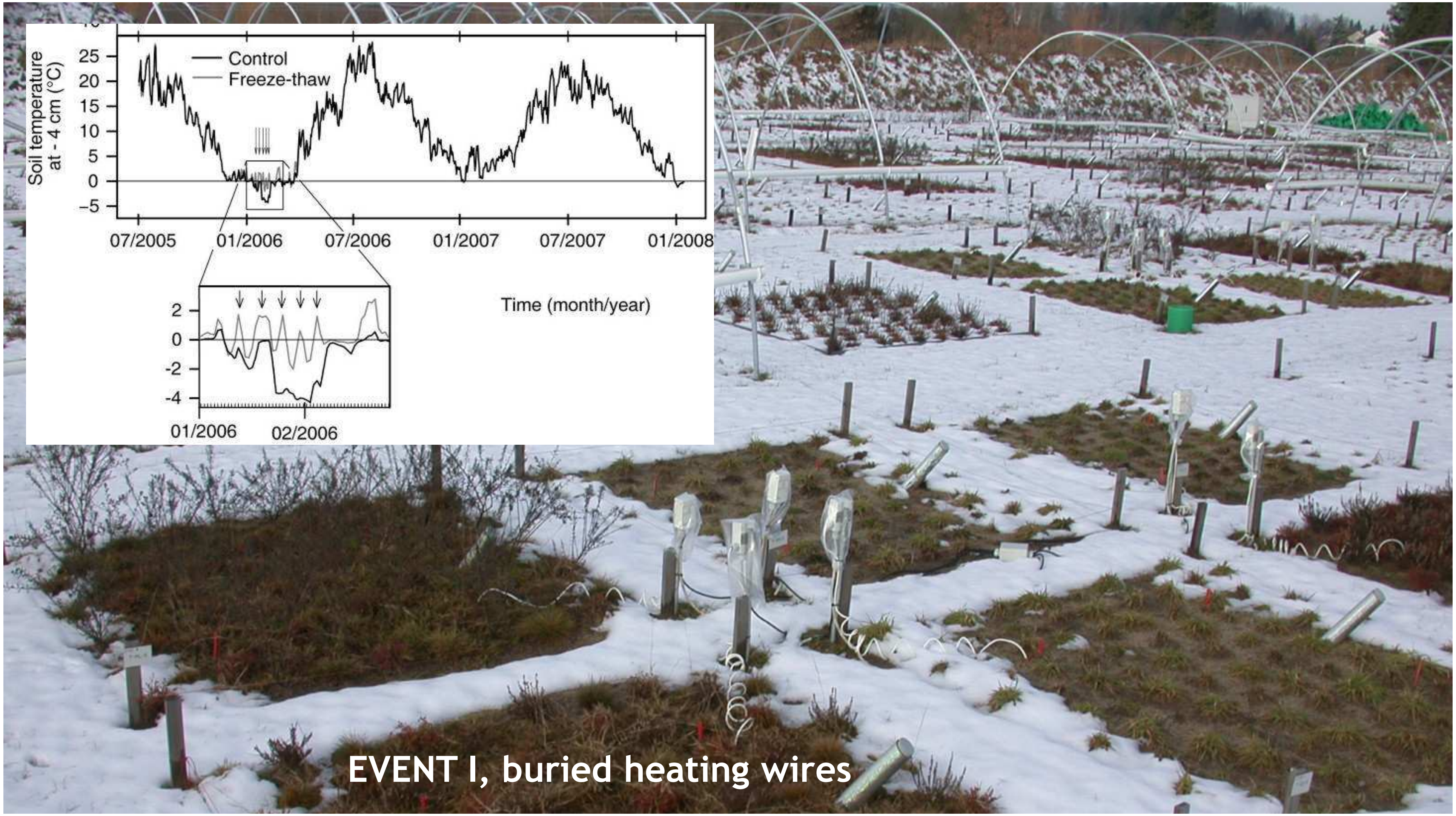
# Winter climate change effects on ecological processes

# *Manipulations*

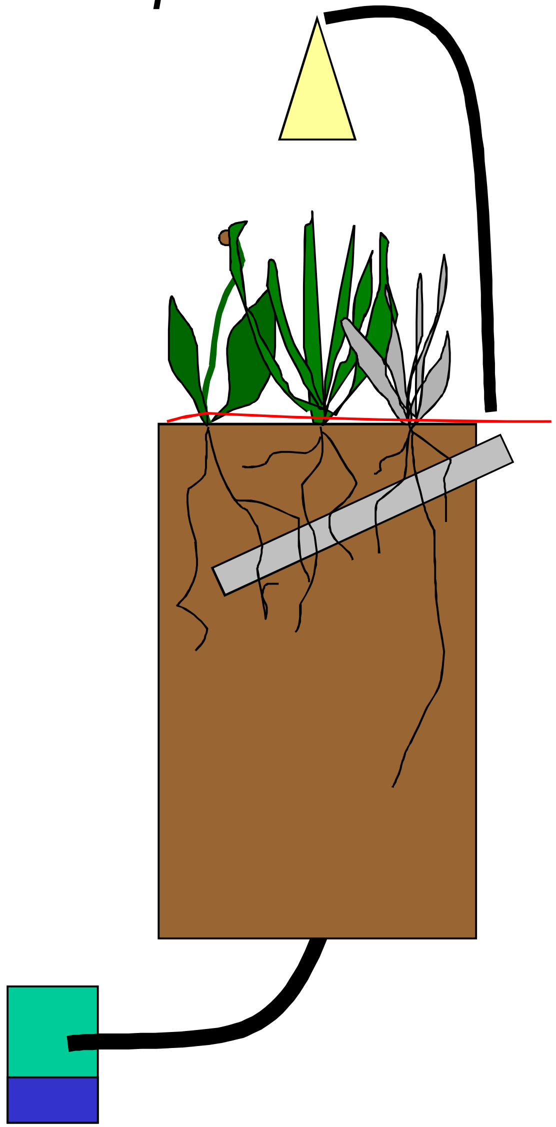
Freeze-thaw cycles: 5 x 3 days in 2005/2006

Heating by buried heating wires before planting in 2004

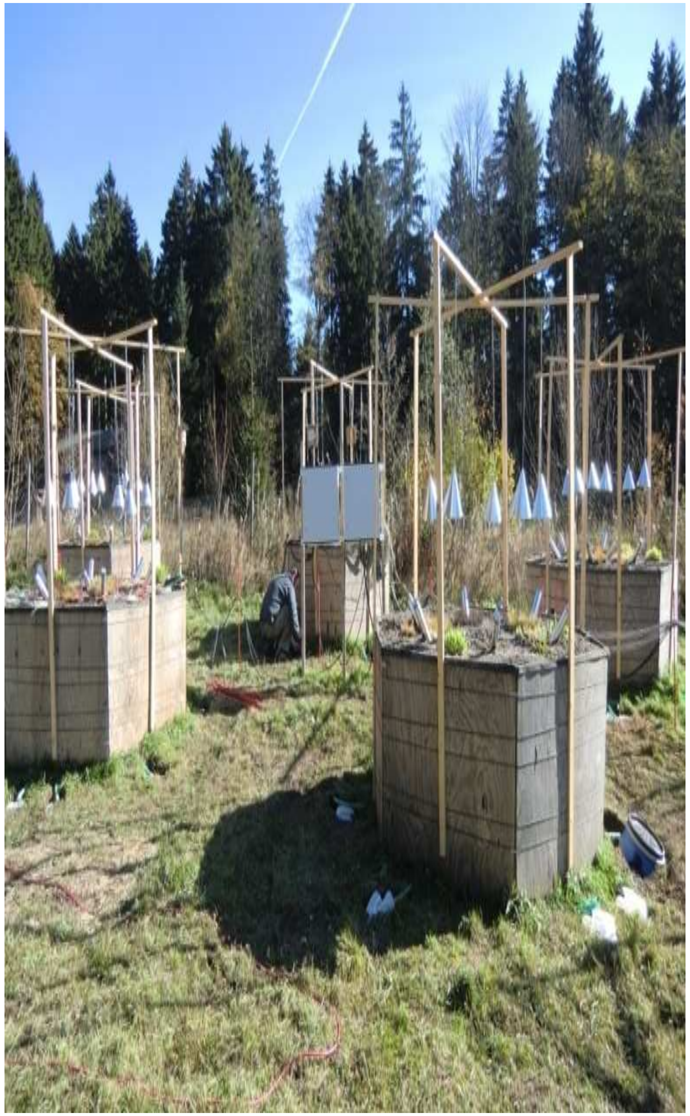


*DFG: JE 202 /6-1 „Events hidden in winter warming: Effects of recurrent soil freeze-thaw cycles on plant performance in the temperate zone“*

*Above ground net primary production, root injury, nutrient leaching, decomposition*



*DFG: JE 202 /6-1 „Events hidden in winter warming: Effects of recurrent soil freeze-thaw cycles on plant performance in the temperate zone“*



# *Neues Experiment: EVENT IV a&b*

***„Events hidden in winter warming: Effects of recurrent soil freeze-thaw cycles on plant performance in the temperate zone“***

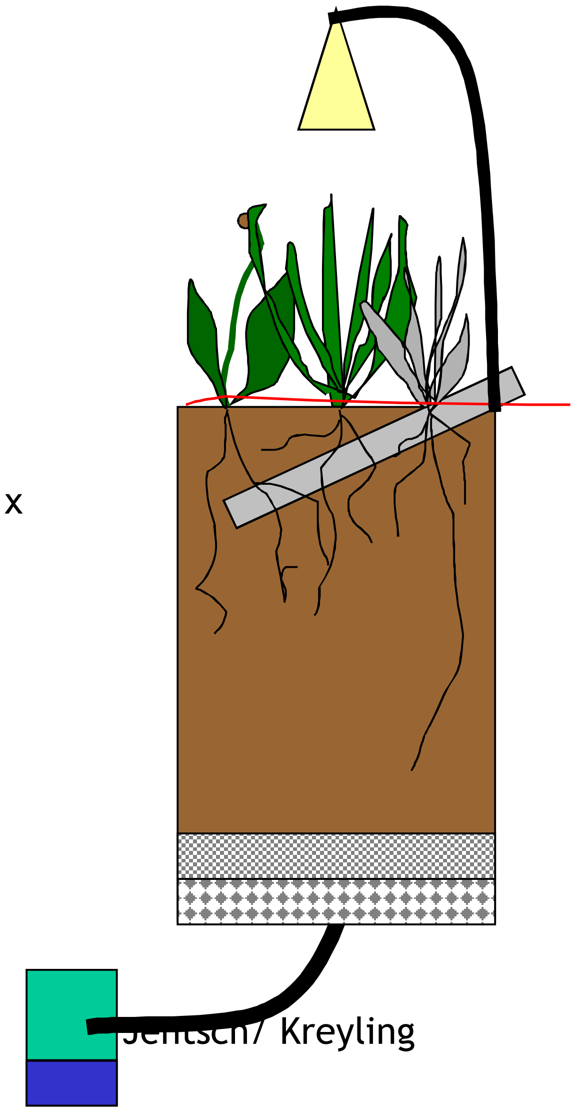
**Ziel:** Auswirkungen von vermehrten Bodenfrostwechseln/ winterlichen Erwärmungspulsen auf Vegetation und Bodenprozesse erfassen

**Methode:** repliziertes Tonnenexperiment (Minilysimeter) im *ÖBG* und *Fichtelgebirge*, Erwärmung durch IR-Strahler in Bodenfrostphasen oder Schneephasen

**Artenzusammensetzungen** (16 Pflanzen pro Tonne):
*Calluna vulgaris* und *Deschampsia flexuosa*
*Holcus lanatus* und *Plantago lanceolata*
Monokulturen aller Arten

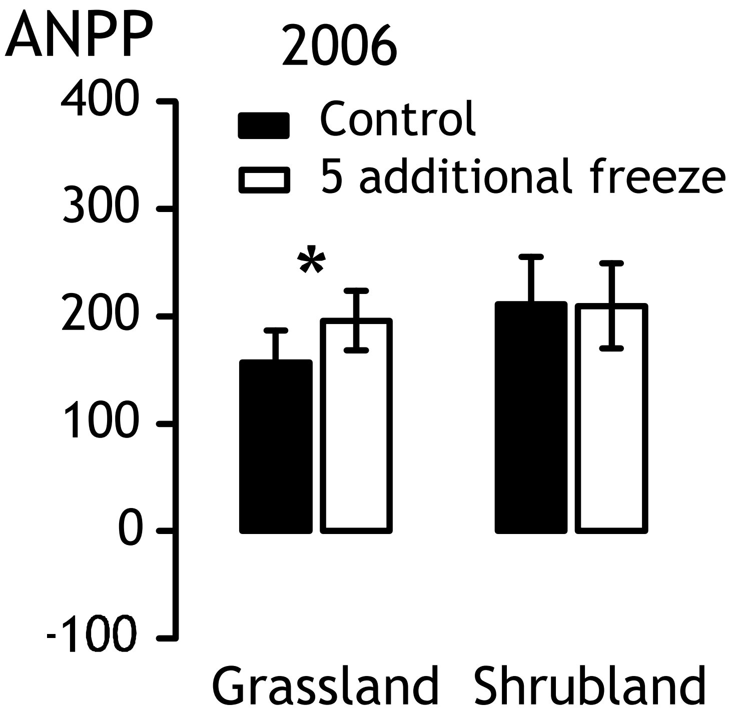
**Umfang:** 6 Communities + bare ground x 2 Standorte x 2 Behandlungen x 5 Wdhlg = 140 Tonnen

**Messparameter:** ANPP, BNPP und Wurzelschäden (Minirhizotrone), Nährstoffe in Boden, Bodenwasser und Pflanzen, Respiration, Frosthärte Wurzeln und Triebe, Photosynthese im Winter, Mykorrhizierung



Jentsch/ Kreyling

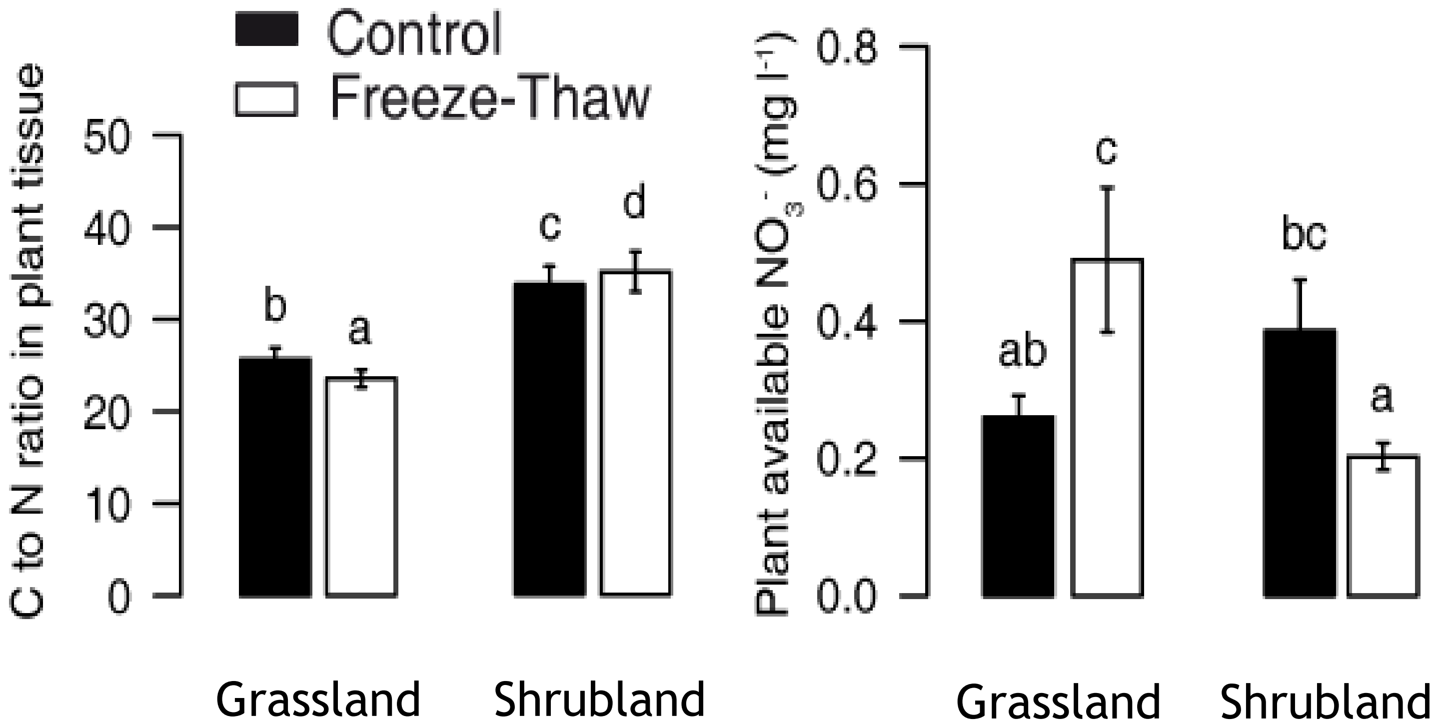
# *Freeze-thaw cycles - ANPP*




Winter freeze-thaw cycles have (delayed) impact on plant productivity, ecosystem effects

Kreyling, Beierkuhnlein, Pritsch, Schloter, Jentsch (2008) *New Phytologist*

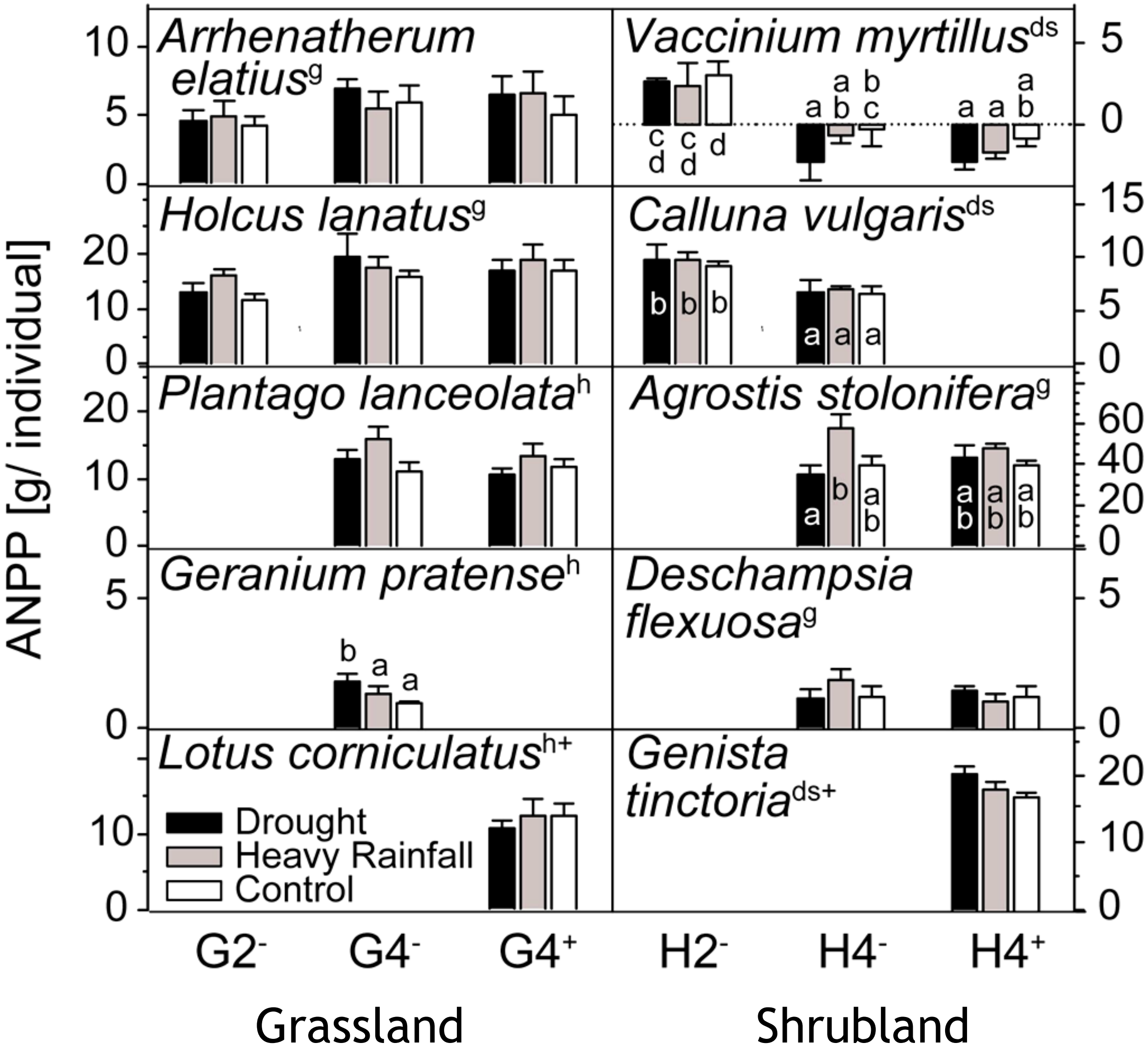
# *FTC: C/N – Ratio in summer leaves and available NO3 in soil*




Complementary effects of freeze-thaw cycles on C/N - ratio in plant tissue and available soil $NO_3^-$ in grassland versus shrubland

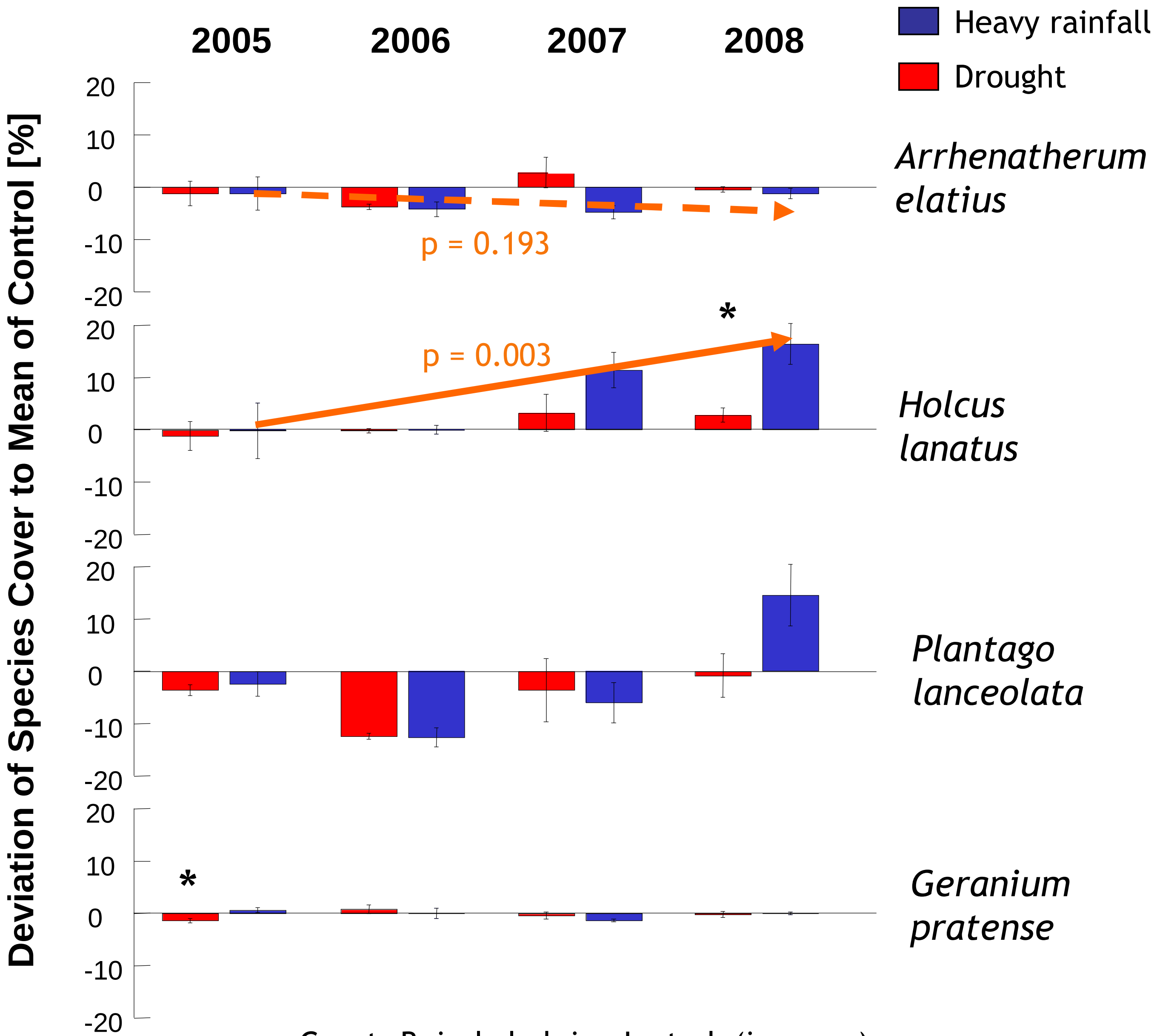
Kreyling, Beierkuhnlein, Jentsch (in press) *Basic and Applied Ecology*

# *Productivity - Species*



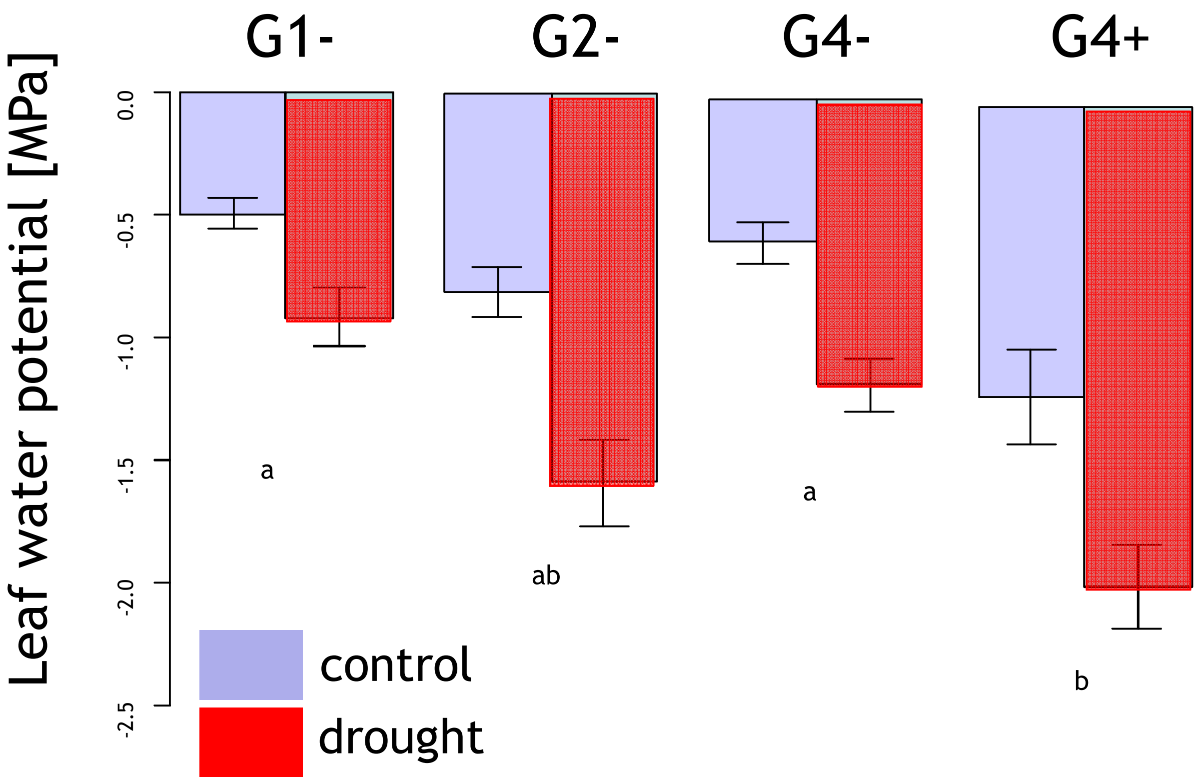

Kreyling, Wenigmann, Beierkuhnlein, Jentsch (2008) *Ecosystems*

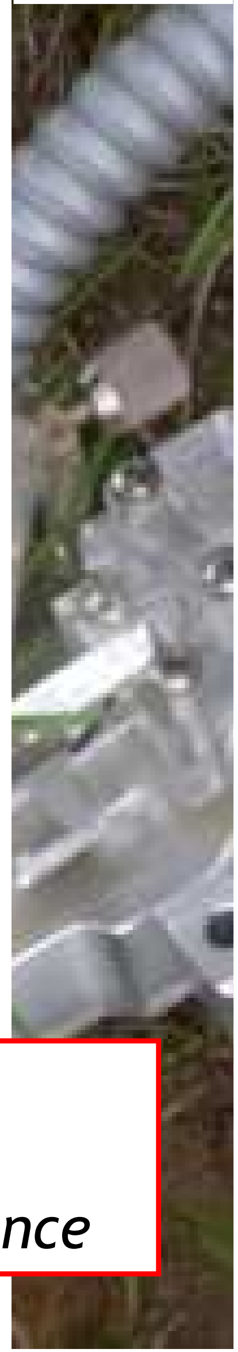
# Species Abundance Shifts - 4 Yrs




Grant, Beierkuhnlein, Jentsch (in prep.)

# *Predawn Leaf Water Potential*
# *Holcus lanatus*

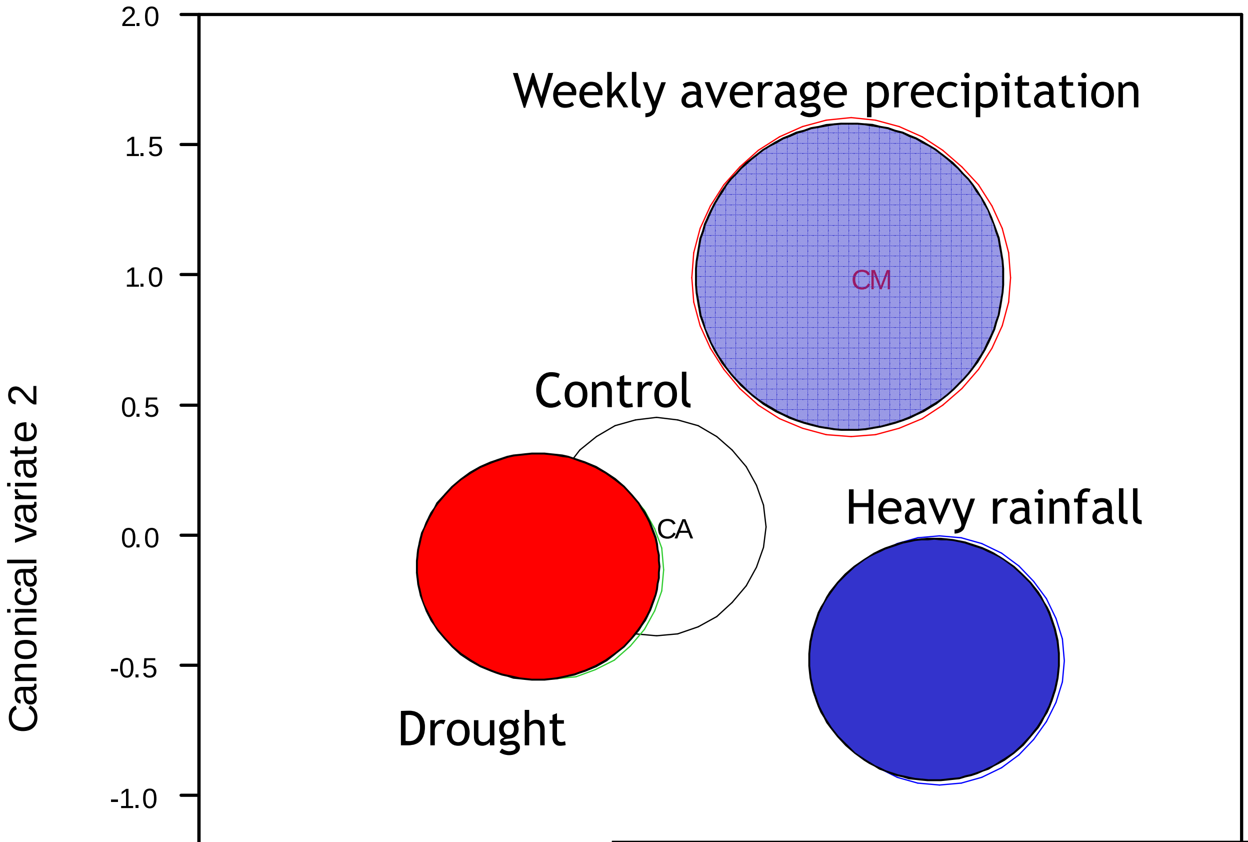


*Diversity effects after drought:*
*LWP lowest in rich communities with legume*
*Community effects on individual physiological perfomance*

Walter, Rascher, Veste, Jentsch (in prep.)

# *Microbial Community Composition*




*No drought effect. Heavy rainfall and weekly average precipitation alters microbial community composition*

| | % | Anova weather | Anova vegetation | Anova Habitat | Anova Weather/habitat weather | weath.hab |
|---|---|---|---|---|---|---|
| PC1 | 33,22 | 0,927 | 0,841 | <.001 | 0,79 | <.001 |
| PC2 | 13,09 | 0,17 | 0,224 | 0,438 | 0,152 | 0,053 |
| PC3 | 10,26 | 0,893 | 0,806 | 0,007 | 0,856 | <.001 |
| PC4 | 7,88 | <.001 | 0,298 | 0,338 | <.001 | 0,034 |
| PC5 | 6,63 | <.001 | 0,32 | 0,512 | <.001 | 0,829 |

Singh et al. (in prep)

**Table 1. Key findings of experiments manipulating weather events[1]**

| *Observed effect* | *Manipulation* | *Sources* |
|---|---|---|
| Reduced aboveground productivity | Drought | Borghetti *et al.* 1998; Gordon *et al.* 1999; Sternberg *et al.* 1999; Grime *et al.* 20 2001; Llorens *et al.* 2002; Filella *et al.* 2004; Gorissen *et al.* 2004; Llorens *et al.* Penuelas *et al.* 2004b; Kahmen *et al.* 2005; Le Roux *et al.* 2005; Erice *et al.* 200 |
| | Rain and drought[2] | Fay *et al.* 2000; Fay *et al.* 2002; Knapp *et al.* 2002; Fay *et al.* 2003 |
| | Frost | Weih and Karlsson 2002; Martin and Ogden 2005; Oksanen *et al.* 2005 |
| | Heat | Marchand *et al.* 2005; Musil *et al.* 2005; Marchand *et al.* 2006 |
| | Drought and heat | Roden and Ball 1996; Ferris *et al.* 1998; Hamerlynck *et al.* 2000; Shah and Paul Xu and Zhou 2005 |
| Reduced belowground productivity | Drought | BassiriRad and Caldwell 1992; Beier *et al.* 1995; Asseng *et al.* 1998 |
| | Rain | Martin and Ogden 2005 |
| Altered species compensation | Drought | Grime *et al.* 2000; Buckland *et al.* 2001; Koc 2001; Lloret *et al.* 2004; Schwinnin |
| | Rain | Sternberg *et al.* 1999; Gillespie and Loik 2004 |
| | Rain and drought | Knapp *et al.* 2002; Bates *et al.* 2005; English *et al.* 2005 |
| | Heat | White *et al.* 2000, 2001 |
| Reduced reproductive success | Drought | Fox *et al.* 1999; Gordon *et al.* 1999; Lloret *et al.* 2004; Morecroft *et al.* 2004; Pe 2004b; Llorens and Penuelas 2005; Lloret *et al.* 2005; Schwinning *et al.* 2005 |
| | Rain | Germaine and McPherson 1998; de Luis *et al.* 2005 |
| | Drought and heat | Shah and Paulsen 2003 |
| | Heat | Liu *et al.* 2006 |
| Altered phenology | Drought | Llorens and Penuelas 2005 |
| | Rain and drought | Fay *et al.* 2000; Penuelas *et al.* 2004a |

[1]Table is based on 46 peer-reviewed publications. Bibliography is available in WebPanel 1.
[2]Rain and drought comprise manipulations of rainfall variability with intensified rainfall events as well as increased drought intensities.